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Sediment Properties off Cairns (A Report on Data obtained in August 1996)

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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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(A Report on Data obtained in August 1996)

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ABSTRACT

This report describes the properties of sediments off Cairns, North Queensland, obtained from samples gathered during trials with A.M.s Brolga and Bermagui in August 1996. These data were obtained in a survey of seabed properties to determine suitable sites and transects for TTCP trials of environmental reconnaissance techniques, which occurred in April/May 1997. The data are relevant to mine burial, acoustic propagation and high frequency reverberation, all important factors in mine warfare. The results form a worthwhile addition to the Mine Warfare Systems Centre and Australian Oceanographic Data Centre data bases, especially as the Cairns area appears to be typical of much of North Queensland's eastern coast and the data herein include much information on sediment shear and bearing strengths, parameters which are critical to impact burial but which are rarely measured.

RELEASE LIMITATION

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Executive Summary

In August 1996, a series of sediment samples were obtained off Cairns, North Queensland, in preparation for a trial under the auspices of the then TTCP G-13 (now MAR-TP-13) Environmental Reconnaissance Specialist Group. This trial was held off Cairns, North Queensland, in April 1977. The sediment properties obtained in August 1996 are presented in this report. The data are relevant to mine burial, acoustic propagation and high frequency reverberation, all important factors in mine warfare. The results form a worthwhile addition to the Mine Warfare Systems Centre and Australian Oceanographic Data Centre data bases, especially as the Cairns area appears to be typical of much of North Queensland's eastern coast and the data herein include much information on sediment shear and bearing strengths, parameters which are critical to impact burial but which are rarely measured.

Contents

Introduction

A group of TTCP nations carried out collaborative trials off Cairns, North Queensland, in April and May 1997. The location of the survey area is shown on a map of Australia in Figure 1. The aims of the trials included (i) a comparison of the performances of a number of acoustic devices for use in seabed classification - RoxAnn, QTC-View (Hamilton et al., 1998) and the New Zealand Acoustic Sediment Profiler, and (ii) a comparison of the performance of a number of internally recording free-fall penetrometers, for estimating seabed bearing strength (Mulhearn et al., 1998). Australia's roles included a survey of the area in 1996, described below, and providing data on sediment properties, especially sediment shear strength, during the 1997 trials.

As a preliminary to the 1997 trials it was necessary to survey various areas so as to find suitable locations for the trials, covering as wide a range of sediment types as possible, but with each site being reasonably homogeneous in itself - i. e. no rapid changes in sub-surface layers, or marked changes in surface sediment type or surface roughness. This survey was carried out off Cairns in August 1996. The data obtained are worth recording firstly because the area off Cairns appears to be typical of much of the east coast of north Queensland, and secondly because of the amount of information gathered on the rarely obtained, sediment shear and bearing strengths. These sediment strengths are critical for the prediction of mine burial on impact. The ships used for the measurements were the RAN's A. M. Brolga and A. M. Bermagui. Station positions are shown in Figure 2 and are listed in Tables A1 to A3, along with data obtained at each position. (All tables are in Appendix A).

2. Experimental Methods

Data were obtained from sidescan sonar runs, from a RoxAnn acoustic seabed classification system, and at a number of stations where sediment and water properties were measured and samples gathered for later analysis. The list of stations occupied and data obtained at each are listed in Tables A1 to A3.

Navigation was by a Differential GPS system consisting of a Furuno GPS Navigator GP-500, with differential corrections provided via the Landstar satellite differential GPS service, which has a land reference station at Cairns . The system gave a positional accuracy of ± 5 m.

2.1 Station Data

Box-cores, Gravity cores and grabs obtained on A.M. Brolga were all taken off the starboard side using the HiAb crane. The New Zealand Electronic Sediment Penetrometer (ESP) was deployed nearly directly opposite this, on the port side, as

was the Submersible Data Logger (SDL), which recorded, temperature, depth and salinity.

2.1.1 Box Core Stations

At the stations listed in Table A1, and shown in Figure 3, which were all occupied by A.M. Brolga, box cores were obtained with an Ocean Instruments box corer having a box 0.6 m deep with a 0.3 m by 0.21 m cross section. One side of the box was removable. On most box core samples the following data were obtained:
(i) surface shear strength with a Geotester pocket penetrometer using a 25 mm diameter plunger;
(ii) a shear strength profile using a hand operated vane shear device with 38 mm square vanes at right angles, torques being measured with a Torqueleader torque wrench with a 0 to 0.50 Nm range;
(iii) a sediment bulk density profile by a gravimetric method (see below);
(iv) a sound speed profile by the time delay method (see below);
(v) photographs of the top and of the side of the box sample.

For the shear strength measurements, the vane shear device was inserted to a specified depth and the vane turned by hand at approximately 90°/minute. In sediments with some shell it was not really possible to turn the vane at a constant rate but the rate was kept as near constant as possible. In all cases the torque rose to a maximum value and then decreased and tended to plateau out. However in some cases it continued decreasing. Peak undrained shear strength was found from the value at the peak using the standard formula:

$$S = T/(3.1416(H*D*D/2 + D*D*D/6)), \qquad (1)$$

where S = peak undrained shear strength (i.e. strength, after loading, when interstitial water has no time to drain out),
T = torque,
H = vane height,
D = vane width.

To use this formula one has to assume the following (Lee, 1985):
(i) that the surface over which shearing occurs is a cylinder with diameter, D, and height, H;
(ii) that failure occurs at the same time over the whole of the cylinder - top, bottom and side;
(iii) that the shear strength is the same on both horizontal and vertical planes;
(iv) that failure occurs too quickly for any drainage of pore water to occur.

Because assumption (i) and (iv) tend to break down in granular sediments, vane-shear devices are considered to be unreliable for sandy sediments (Wilson, 1963), but reliable for cohesive sediments. However as will be seen below, they still gave results in non-

cohesive sediments which often agreed with a penetrometer, within experimental scatter.

To obtain sub-samples, for sediment bulk density measurements, a flat plate was first placed in the corer's box, on top of the sediment, to hold it in. Then the box was tipped on its side and the side of the box was removed. A series of tube were then inserted into the side of the sediment sample so as to fill the tubes with as little disturbance to the sediment as possible. These tubes were then weighed on board ship with a set of Wedderburn scales with a range of 0 to 1.0 kg. The sampling tubes were of plastic, weighed 0.106 gm, were 57 mm diameter and 218 mm long. A weakness of this method is that air spaces may occur within the tubes, giving an underestimate of bulk density, but care was taken to avoid this.

Sound speeds were obtained by measuring, over a fixed distance of 87 mm, the time delay between transmission and reception of a 2 cycle, 50.0 kHz, 7.51 volt pulse, with a sweep interval of 46.5 msec. An LC10 hydrophone was used as the projector and a CH-17 Clevite hydrophone as the receiver. The block diagram for the measurements is shown in Figure 4. The transmit pulse was generated with a HP331AF Function Generator. The received pulse was passed through a Wavetek Rockland Model 852 Dual High/Low Filter to remove noise. For eight stations the received signal was band-passed between 4 and 90 kHz, but for stations 1, 2, 3, 6, 7 and 8 no filters were used. After filtering, the signal was amplified by either 30 or 40 dB using a low noise amplifier built at DSTO, Sydney. The transmitted and received signals were then recorded on a NEC Versa Notebook Computer set in a NEC docking station with a Gage Applied Sciences CompuScope IBM PC-based digital oscilloscope and data acquisition board. The transmitted pulse was passed through a 50 ohm, 10 dB attenuator immediately before it went to the Docking Station. At each depth in a box-core sample, ten pairs of transmitted and received pulses were recorded, for later averaging. Measurements were also taken in fresh water, to provide a reference. At the same time as these last measurements, water temperature was measured. Time delays through the electronics of the receiving system were also measured, so that the true time delays in water and sediment could be obtained. The accuracy of the ratio of sound speed in the sediment to that in the water is estimated as ± 2%.

Other data obtained at most box core stations were:

(i) sea surface temperature with an under-way bucket and mercury in glass thermometer;

(ii) sea surface salinity via a surface water sample, later analysed in the laboratory;

(iii) vertical water temperature and salinity profile with a Yeo-kal Submersible Data Logger (SDL);

(iv) video film of the sea floor, with a Sony Video camera Handycam Video 8 mounted in a protective frame, which was lowered to just above the sea floor and then allowed to drift with the ship over the bottom.

The temperature and salinity data will not be discussed in this report, but they will be available from the Australian Oceanographic Data Centre.

Most box-core stations were reoccupied to obtain bearing strength data with a New Zealand Electronic Sediment Probe (ESP), which is described in Hurst et al. (1996) and in Appendix B, but box-cores and ESPs were used on the same occasion at both stations 4 and 5.

At eight stations cores were also obtained with a 5" diameter Wildco gravity corer, whose samples were kept for later laboratory analysis. Most stations were covered by sidescan sonar swathes.

2.1.2 Sediment Grab Stations

At the stations indicated in Tables A2 and A3 sediment samples were taken using a Shipek grab, from A.M.s Brolga and Bermagui, respectively. At two shallow water stations bottom samples were obtained with a small pipe dredge, from A.M. Brolga's Zodiac. At many of the grab stations, occupied by A.M. Brolga, the ESP was also deployed.

2.2 Sidescan Data

Sidescan sonar runs were carried out, by both A.M. Brolga and A.M. Bermagui, along the tracks listed in Table A4. The equipment consisted of a Klein 595 Digital Sonar linked to a data acquisition system manufactured by Info Express Inc. and a Quills II Navigation and Data Management System, made by Meridian Ocean Systems. The sidescans operated at 100 and 390 kHz. These data are discussed more fully by Anstee (1998).

2.3 RoxAnn

A RoxAnn acoustic seabed classification system was run almost continuously each day from when Brolga left the wharf to when it returned. Data coverage and a discussion of the results are fully covered in Hamilton et al. (1998).

2.4 Laboratory Sediment Analyses

Laboratory analyses were later carried out on the sediment samples obtained from the box core, grab and dredge. The muddier samples were sent to the Ocean Sciences Institute, University of Sydney for measurement of porosity, grain density and carbonate percentage by the methods described in Mulhearn and Cerneaz (1994), while particle size distributions within the mud fraction were obtained using a Galai CIS-100 Particle Size Analyser, which determines particle size by using Time of Transition Theory - the time for a laser beam, moving at constant velocity, to pass by a particle is directly related to the particle's size. (Herein the terms mud, sand and gravel refer to size fractions, with mud particles having diameter less than 63 μm, sand particles having diameters between 63 μm and 2 mm, and gravel particles being larger

than 2 mm in diameter. Off Cairns gravel particles are practically always carbonaceous, that is composed of calcium carbonate and of biological origin).

The less muddy sediment samples were analysed at Pyrmont for porosity, grain density and carbonate % while size distributions were determined by sieving. Methods used are described in Mulhearn and Cerneaz (1994).

Dr John Dunlop, Department of Physics, University of New South Wales, carried out the following measurements on the 5" gravity cores from stations 15 and 17, using methods described in Dunlop (1997): (i) ratio of sound speed in the core to that in sea water at the same temperature at 46.4 kHz, 90 kHz, 340 kHz and 1.05 MHz; (ii) the sound speed attenuation coefficients at these frequencies; (iii) shear wave velocity at 1.6 kHz; (iv) porosity; (v) structure function; (vi) permeability.

3. Results

To show the distribution of sediments in the region off Cairns, the percentages of mud and carbonate, found in surface samples, are shown in Figures 5 and 6, respectively. Carbonate material comes from the remains of marine organisms, and low carbonate, unconsolidated material generally comes from the land. The data are compatible with earlier surveys of Jones (1985) and Maxwell and Swinchatt (1970). These showed a wedge of terrigenous (i.e. low carbonate) mud near shore, with sandier sediments near Cape Grafton (approximately 16° 51'S, 145° 53'E), and decreasing mud content and increasing carbonate content as one moves offshore towards Green Island and Arlington Reef. High carbonate muddy sediments were found inside Arlington Reef, in agreement with Maxwell and Swinchatt (1970). In the region of 20% to 30% mud content, south and immediately east of Green Island, surface sediment samples, obtained in this survey, contained over 25% gravel. Near the outer edge of the Great Barrier Reef the sediments had a high carbonate and low mud content. Those east of 146° 15'E contained over 25% gravel, while those west of 146° 15'E contained 10% to 25 % gravel. In many places on the outer reef the gravel contained a high proportion of debris from Halimeda algae, and a reasonable number of forams.

Peak undrained shear strength profiles, obtained with the vane shear device, are shown in Figures 7 and 8, and listed in Table A5. It can be seen that shear strength increases with depth more rapidly at stations with coarser sediments, such as 4, 5, 7, 8, and that at stations 12 and 13, within the shelter of Arlington Reef, where the sediments are muddy carbonate, shear strength values are higher than at other muddy locations. Lowest shear strengths were observed at station 6. (Refer to Figure 3 for box core locations). In Table A6 are presented values of soil sensitivity, the ratio of peak undrained shear strength to the remoulded value, i.e. that after the vane had gone through one revolution. The average of the surface shear strength values, obtained by pocket penetrometer at each box core station, are listed in Table A7.

Sediment bulk density profiles, as obtained aboard ship from sub-samples of box cores, are shown in Figures 9 and 10, and listed, along with other sediment properties in Table A8. Lowest densities, below 0.1 m depth, were found at station 6. A group of stations have densities between 1600 and 1800 kg/m^3, stations 7 and 8 have values between 1500 and 1600 kg/m^3, and station 5 has the largest densities measured. Densities at the inshore stations 1 and 2 have surface values close to those at 6, but then increase with depth towards 1600 kg/m^3. These field bulk densities and other properties of surface sediment samples are listed in Tables A8 and A9. Note that the field bulk densities typically exceed those obtained in the laboratoty.

Carbonate percentage profiles are shown in Figure 11, and listed in Tables A8. At most locations carbonate varies little with depth, and its spatial distribution can be seen from Figure 6. Carbonate percentages, from surface samples are listed in Table A9.

Percentages of gravel, sand and mud, determined by sieving, are listed for coarser sediments in Tables A10 and A11, for box core and surface samples, respectively. Also listed in these tables are carbonate percentages for sand and mud fractions. In Table A12 gravel, sand and mud percentages, as determined by sieving are listed, for muddier sediments. The mud fractions were then analysed for particle size distributions using a Galai CIS-100 Particle Size Analyser (see Section 2.4). It was found that some of the mud fraction, as determined by sieving, was classified as fine or very fine sand by the particle size analyser. The sieve and particle size analyser results were combined by assuming the latter's splits between mud and sand were correct, and then adding in the sieve splits to determine corrected percentages of gravel, sand, silt and clay. The part of the silt fraction (coarse, fine, etc.) whose size range included the modal diameter of the mud fraction was also determined. These are listed in Tables A13 and A14. (Silt particles have diameters between 4 and 63 μm, clay particles have diameters less than 4 μm). For most samples the particle size mode, in the mud fraction, is in the coarse silt size range, i.e. 31 to 63 μm, and clay percentages are generally less than 5%.

Sediment compressional sound speed profiles, measured as described in section 2.1.1, are shown in Figures 12 and 13, and listed in Table A15. Sound speeds are mostly between 1490 and 1580 m/s. Exceptions to this are at station 12, where the sediment is a carbonate mud, and the near surface speeds are less than 1490 m/s, and stations 4, 5, 7 and 2, where sound speeds are greater than 1580 m/s. Of these last 4 stations, all except station 2, have coarse sediments. Some of the values at stations 4 and 5 are unusually high, but the reasons for this are not known. As a comparison with the sediment sound speed values, in water values were 1533.87 and 1533.97 m/s at stations 15 and 17, respectively.

The following measurements were obtained by Dunlop on the 5" gravity cores from stations 15 and 17: (i) ratio of sound speed in the core to that in sea water at the same temperature at 46.4 kHz, 90 kHz, 340 kHz and 1.05 MHz; (ii) sound speed attenuation coefficients at these frequencies; (iii) shear wave velocity at 1.6 kHz; (iv) porosity; (v) structure function, g; (vi) permeability, k. These are listed in Table A16. Dunlop's

sound speed ratios (extrapolated to a frequency of 50 kHz, using Biot theory) and porosities are compared with ours, from box cores, in Table A17. Speed ratios agree, within experimental error at station 15 and at the upper level from station 17, but box core values are lower for the lower level at station 17. Porosities agree within 0.03, i.e. 6%, but one would expect better agreement. However the differences between gravity core and box core results may be due to spatial inhomogeneities. There are insufficient data to detect systematic differences, between the two approaches to measuring sound speed.

Descriptions of the box core samples from visual observations, made on board ship, are presented in Table A18, and descriptions of video-film footage of the sea floor may be found in Appendix C.

Comparisons between bearing strength values obtained from the Electronic Sediment Probe (ESP), which is described in Appendix B, and the vane shear measurements are presented in Figures 14 to 20. Multiple drops were obtained with the ESP at each station. Bearing strength from the vane shear measurements is taken as ten times the peak undrained shear strength. Ten is a typical multiplication factor for a long thin body like the ESP. It can be seen that at most sites vane shear results lie within the spread of the ESP data. Notable exceptions are the results from stations 2 and 5. Differences between vane shear and ESP data at station 2 could have been due to spatial variability at this station, and difficulty in occupying exactly the same location on two different days. At station 5 there is considerable variability between the results from individual ESP deployments, so that the difference between vane shear and ESP data may simply reflect a high spatial variability in sediment properties at this particular site. The ship was only anchored at the bow, so the stern could have moved around to some extent. The ESP drops at stations 4 and 5 achieved very little penetration and the data show a definite peak in bearing strength, with lower bearing strength values below it in the sediment (Figures 17 and 18). The values below the peak are probably unreliable. The most likely explanation is that the ESP fell over because its shaft had such little penetration.

ESP deployments obtained without accompanying vane shear measurements are presented, for completeness in the figures of Appendix D. There are data from (i) in-shore sites to the north of Cairns, (ii) a site within the Great Barrier Reef Lagoon, between the coast and Arlington Reef, (iii) sites along the outer edge of the Reef, and (iv) one site near Cape Grafton.

4. Conclusions

The data presented in this report provided a valuable input to the TTCP trials, held off Cairns in April 1997. They are relevant to mine burial, acoustic propagation, and high frequency reverberation, which are all important factors in mine countermeasures operations. The results form a worthwhile addition to the Mine Warfare Systems

Centre and Australian Oceanographic Data Centre data bases, especially as the Cairns area appears to be typical of much of North Queensland's eastern coast and the data herein include much information on sediment shear and bearing strengths, parameters which are critical to impact burial, but which are rarely measured .

5. Acknowledgments

The assistance of the RAN personnel, manning A.M.s Brolga and Bermagui, is gratefully acknowledged. Trials support was also provided by staff at HMAS Cairns. The bulk of the sediment analyses were performed under contract by Ms Alison Cole of the Ocean Sciences Institute, University of Sydney, while analyses of coarser samples were undertaken by Ms Jane Cleary and Mr Barry Scott of DSTO. Mr Paul Clarke assisted with the analysis of sound speed data.

6. Data availability

Data from this cruise will be archived at either the Australian Oceanographic Data Centre, or Maritime Operations Division, DSTO. Further queries about any of the data can be made to either organisation.

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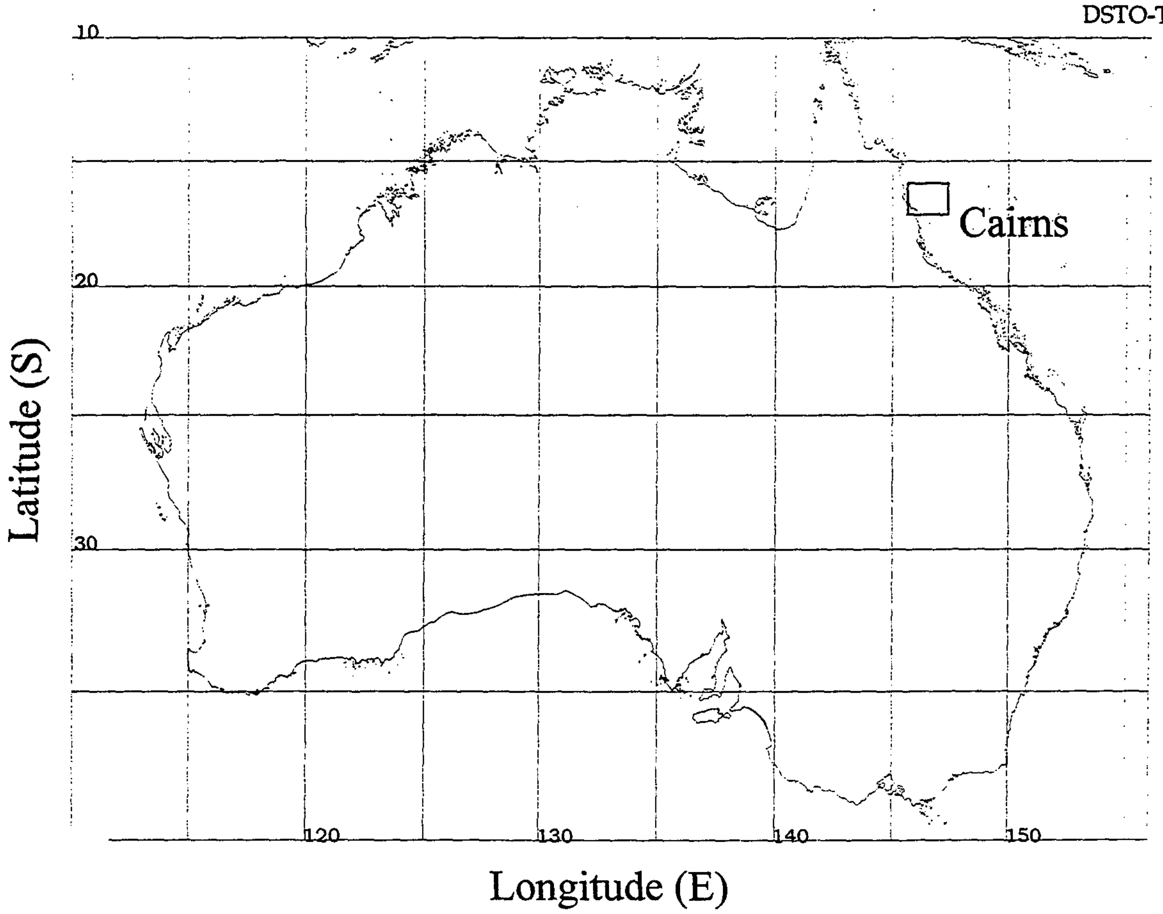

Figure 1. Map of Australia, showing location of survey area.

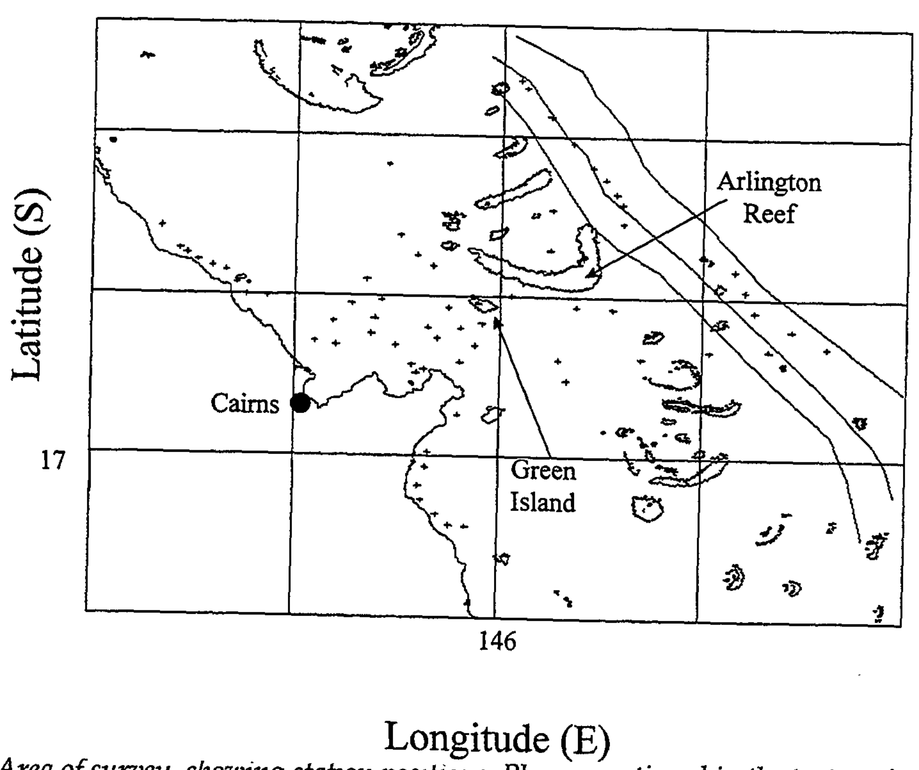

Figure 2. Area of survey, showing station positions. Places mentioned in the text are indicated.

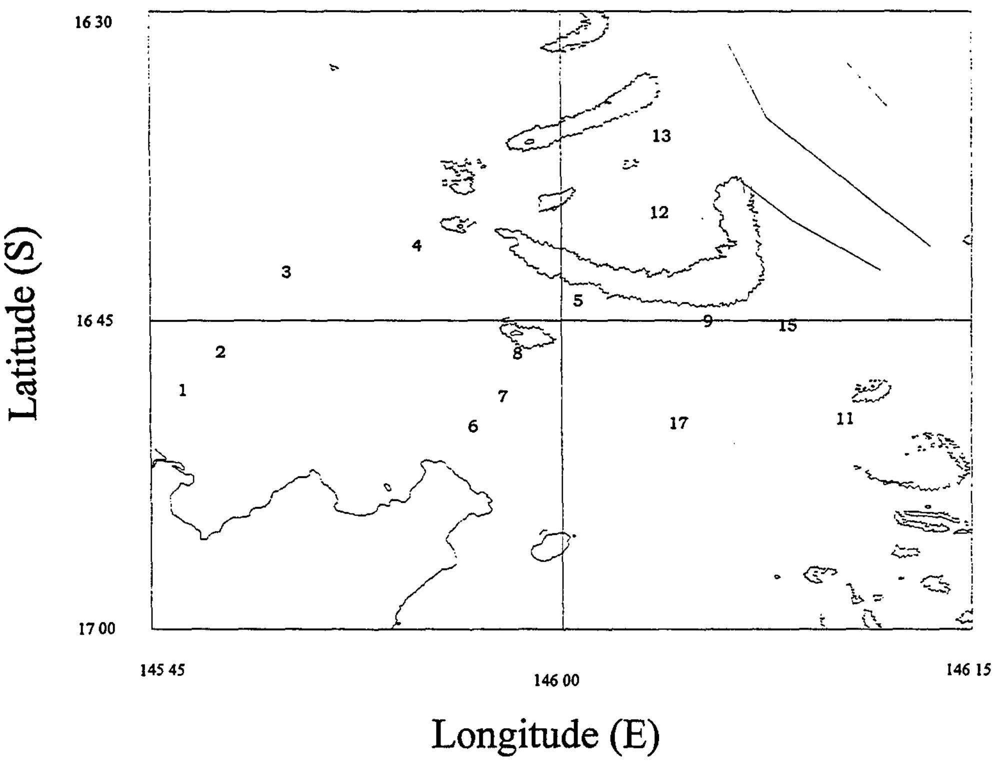

Figure 3. Locations of box-core stations.

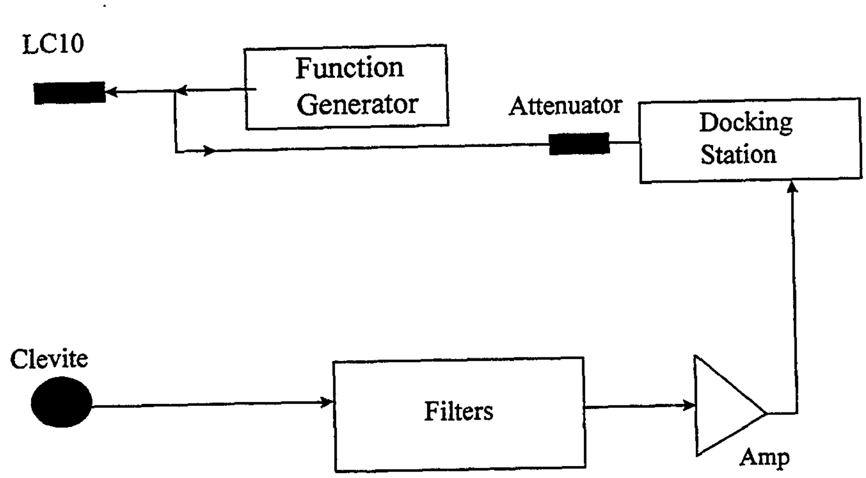

Figure 4. Block diagram of sediment sound speed apparatus.

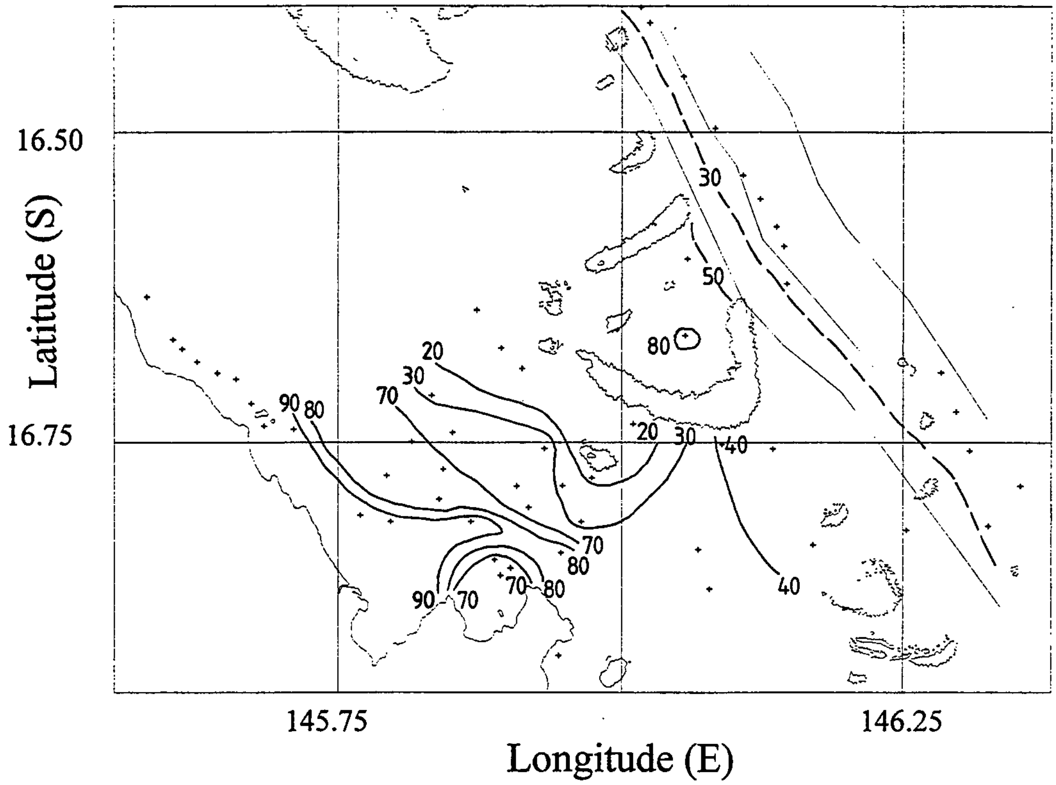

Figure 5. Contours of percentage of mud in surface sediment samples. Note the rapid transition from 70% to 30% mud as one moves off-shore.

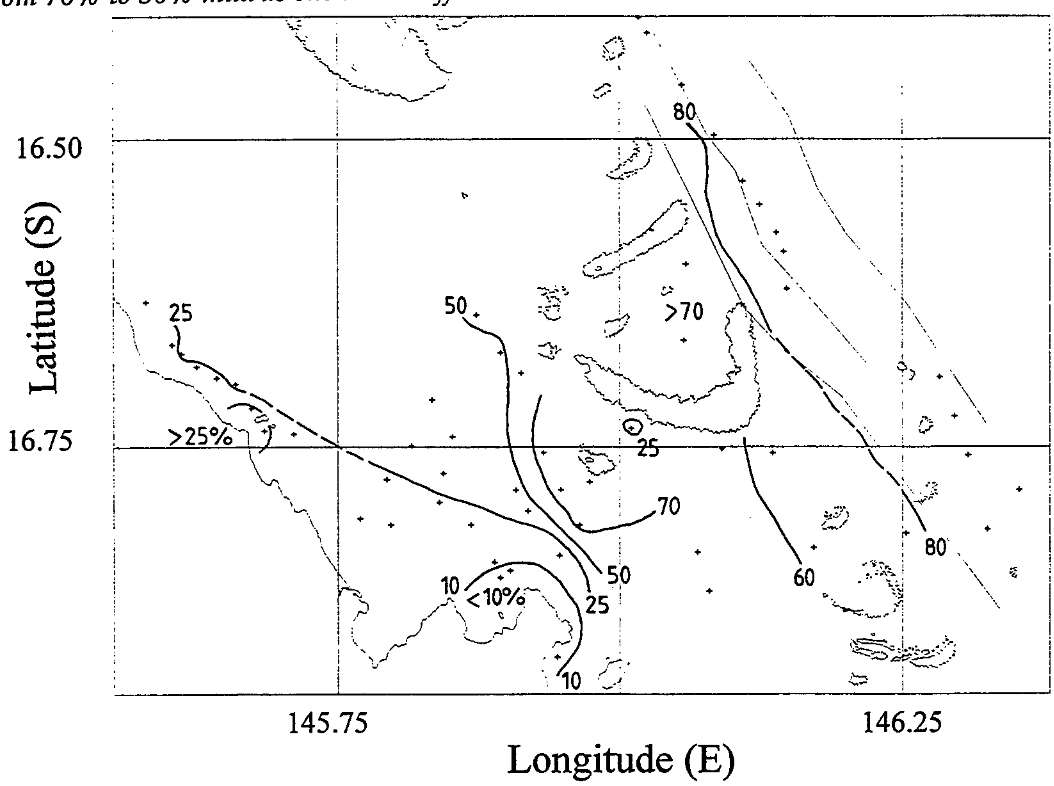

Figure 6. Contours of percentage of carbonate in surface sediment samples. Note the rapid transition from 50% to 70% carbonate as one moves off-shore, towards Green Island.

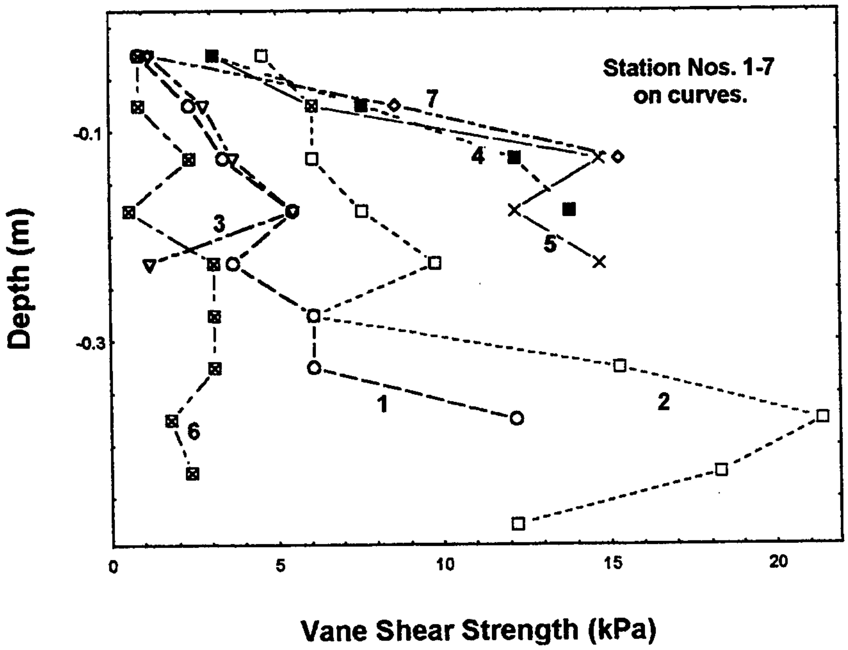

Figure 7. Peak undrained sediment shear strength profiles, from vane shear data at stations 1 to 7.

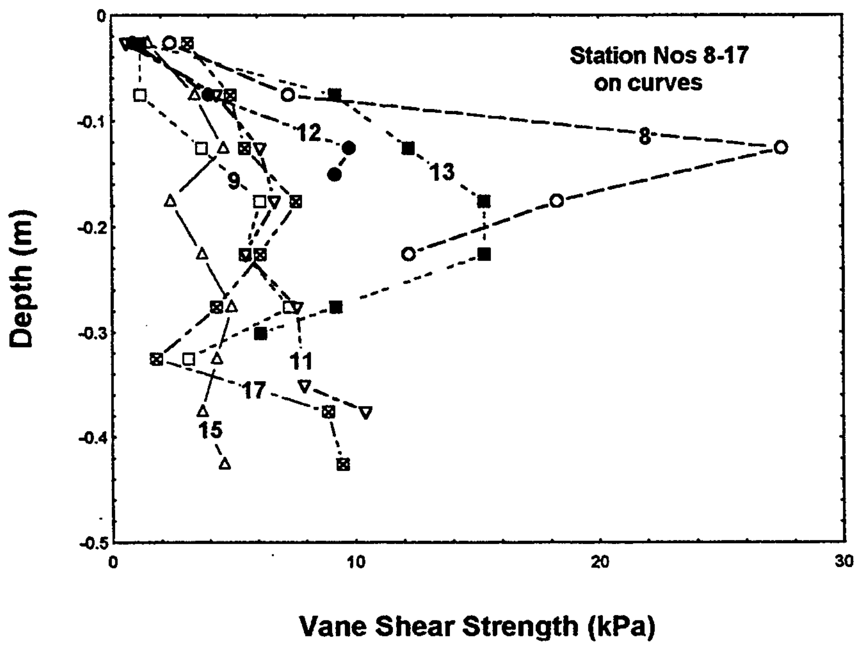

Figure 8. Peak undrained sediment shear strength profiles, from vane shear data at stations 8 to 17.

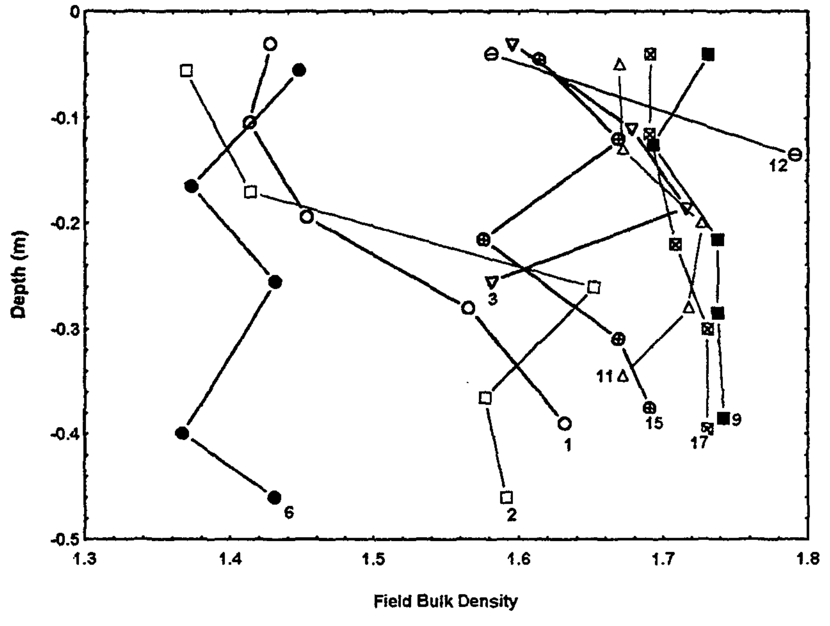

Figure 9. Bulk density profiles for stations with less coarse sediments. (Density units are kg/m³ ÷ 1000)

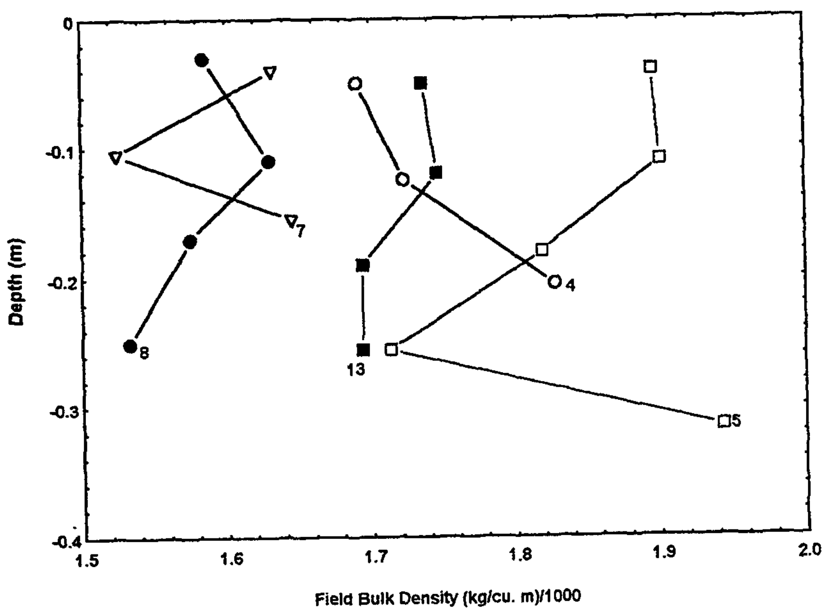

Figure 10. Bulk density profiles for stations with coarser sediments. (Density units are kg/m³ ÷ 1000).

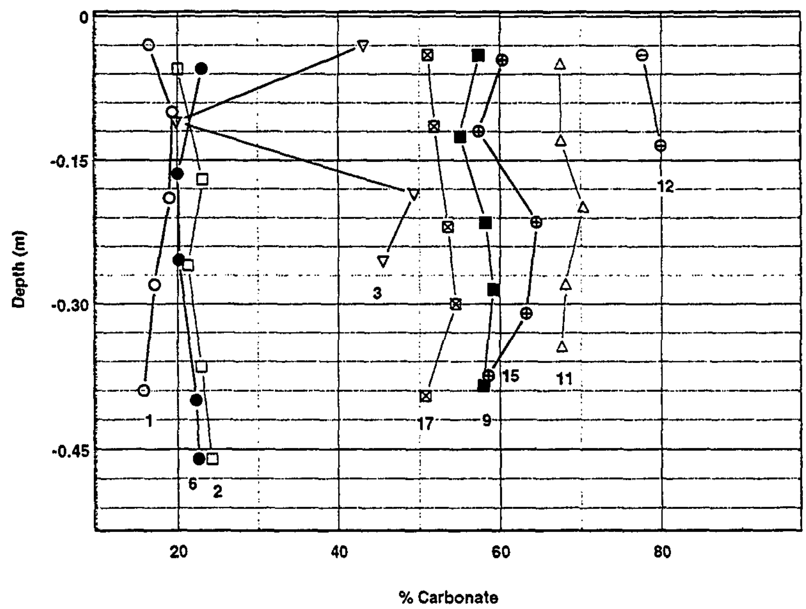

Figure 11. Carbonate percentage profiles.

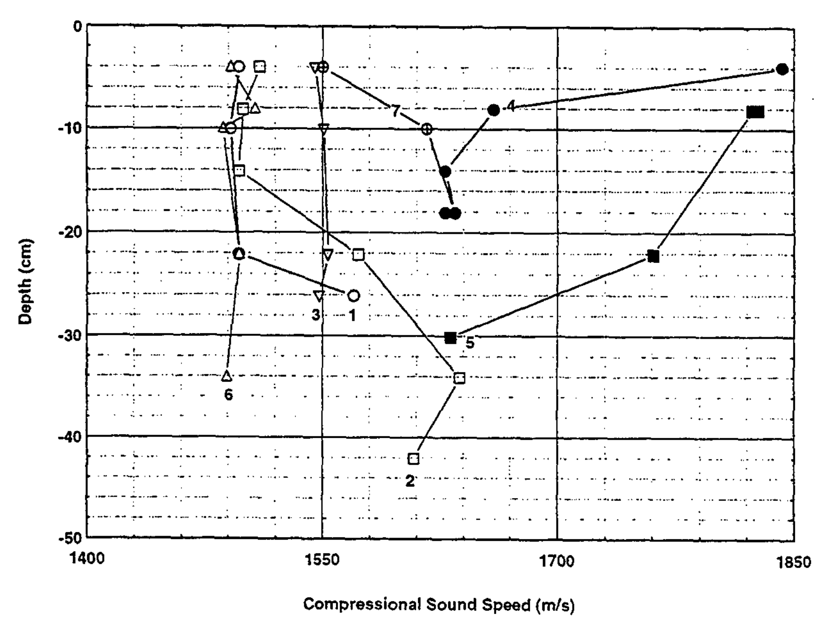

Figure 12. Compressional sound speed profiles, from stations 1 to 7.

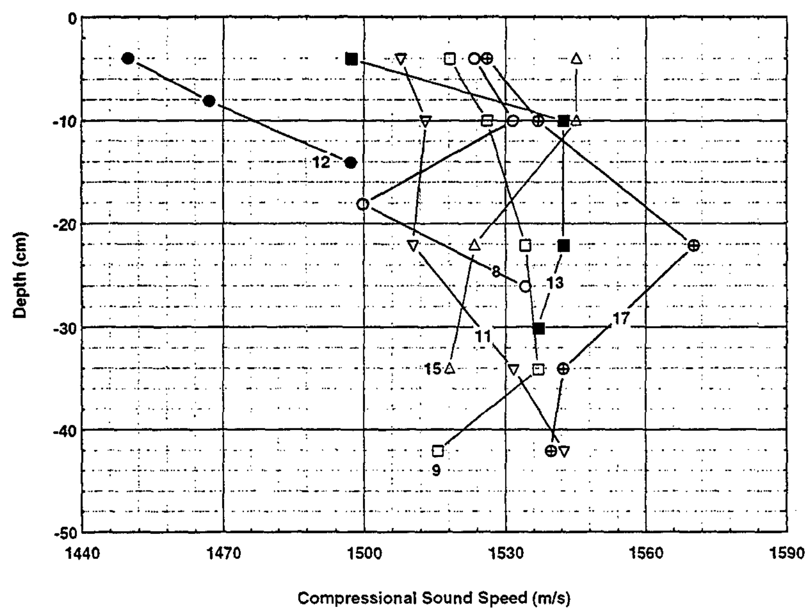

Figure 13. Compressional sound speed profiles, from stations 8 to 17.

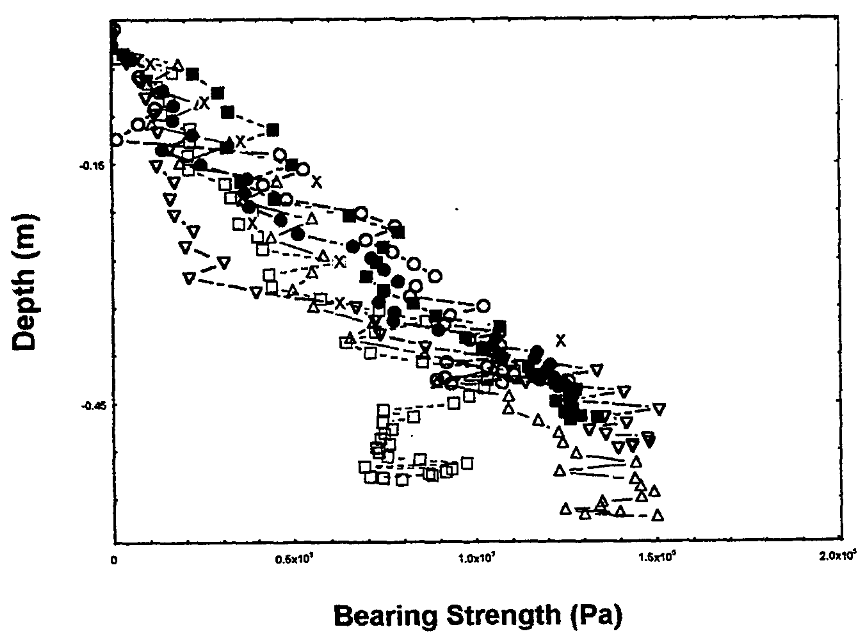

Figure 14. Bearing strength profiles from the ESP versus vane shear results, at station 1. (Vane shear data are indicated by an X; the other symbols are for the different ESP drops).

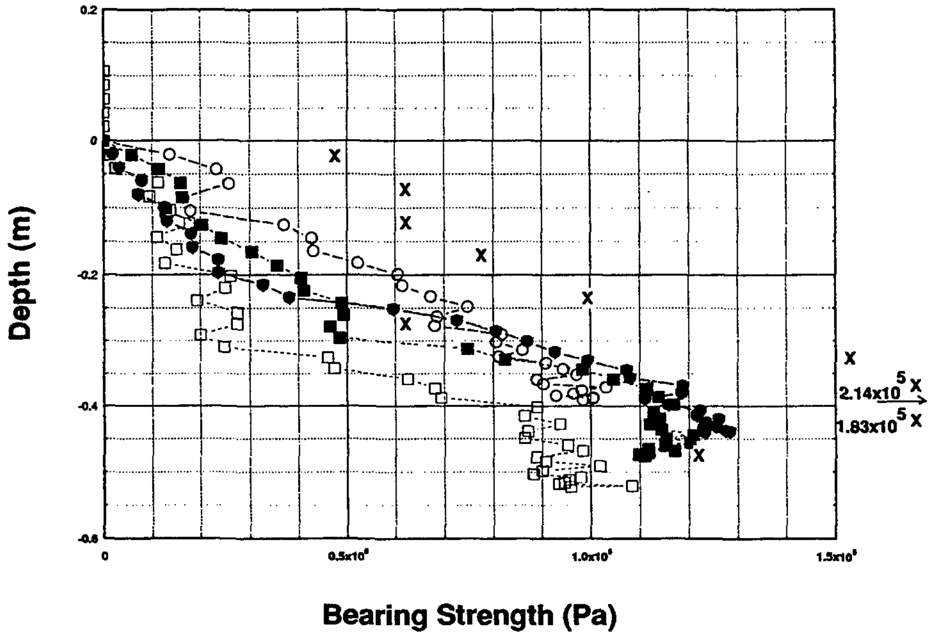

Figure 15. Bearing strength profiles from the ESP versus vane shear results, at station 2. (Vane shear data are indicated by an X; the other symbols are for the different ESP drops).

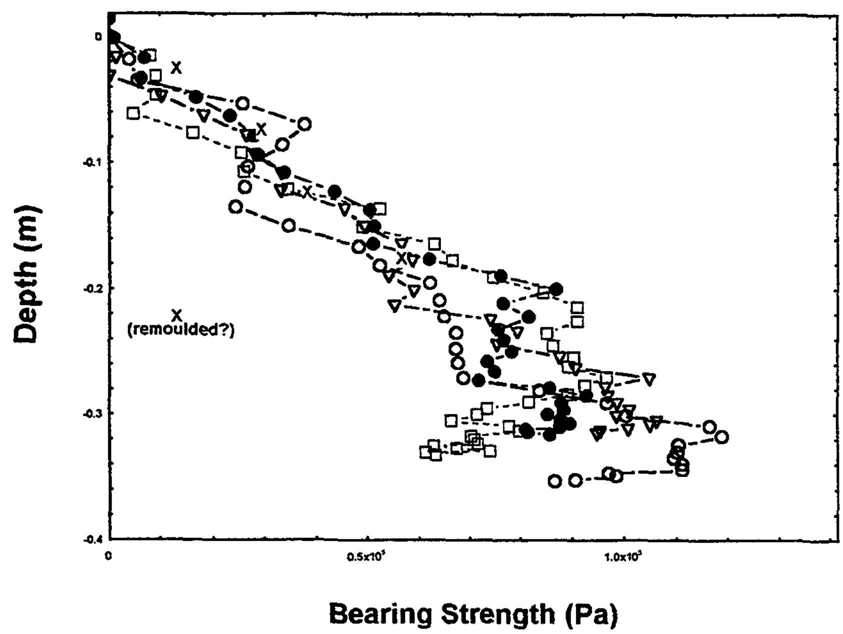

Figure 16. Bearing strength profiles from the ESP versus vane shear results, at station 3. (Vane shear data are indicated by an X; the other symbols are for the different ESP drops).

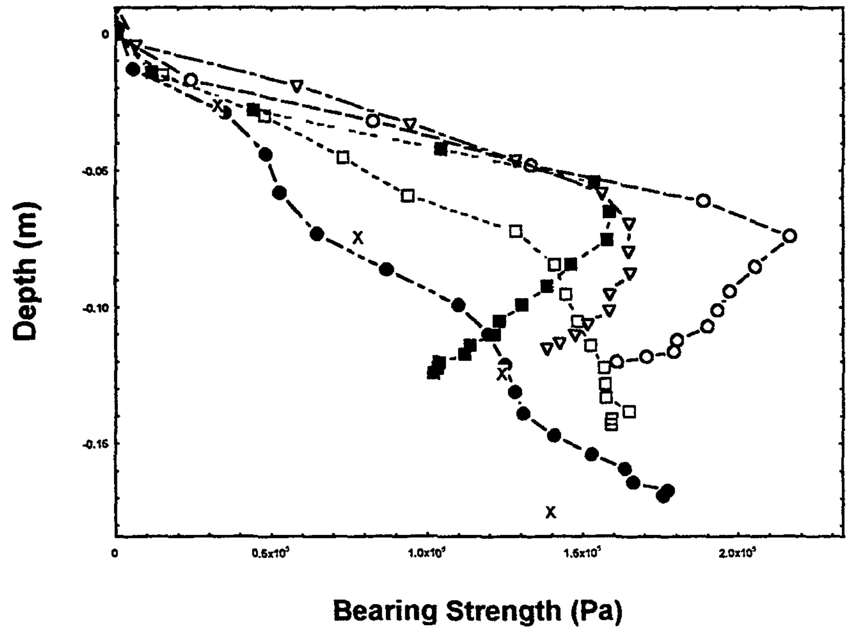

Figure 17. Bearing strength profiles from the ESP versus vane shear results, at station 4. (Vane shear data are indicated by an X; the other symbols are for the different ESP drops).

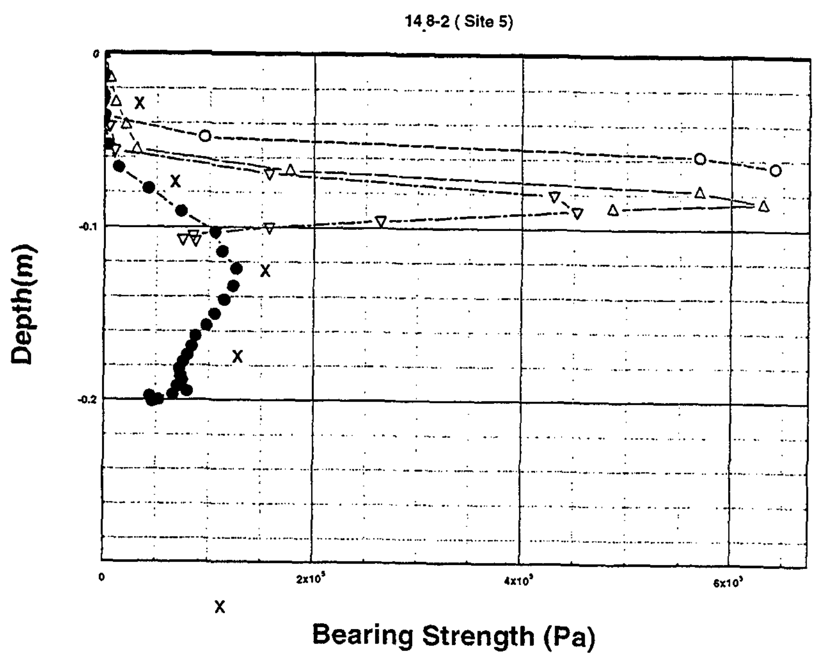

Figure 18. Bearing strength profiles from the ESP versus vane shear results, at station 5. (Vane shear data are indicated by an X; the other symbols are for the different ESP drops).

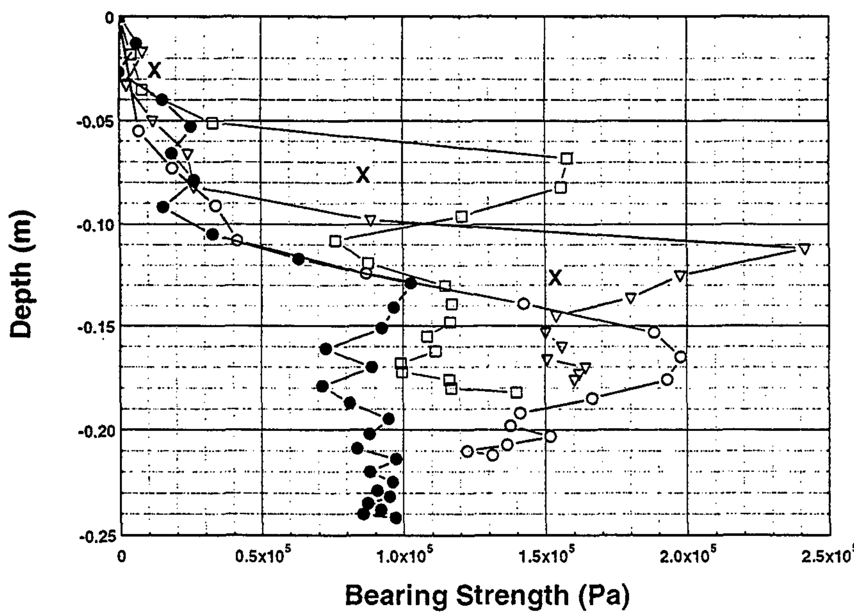

Figure 19. Bearing strength profiles from the ESP versus vane shear results, at station 7. (Vane shear data are indicated by an X; the other symbols are for the different ESP drops).

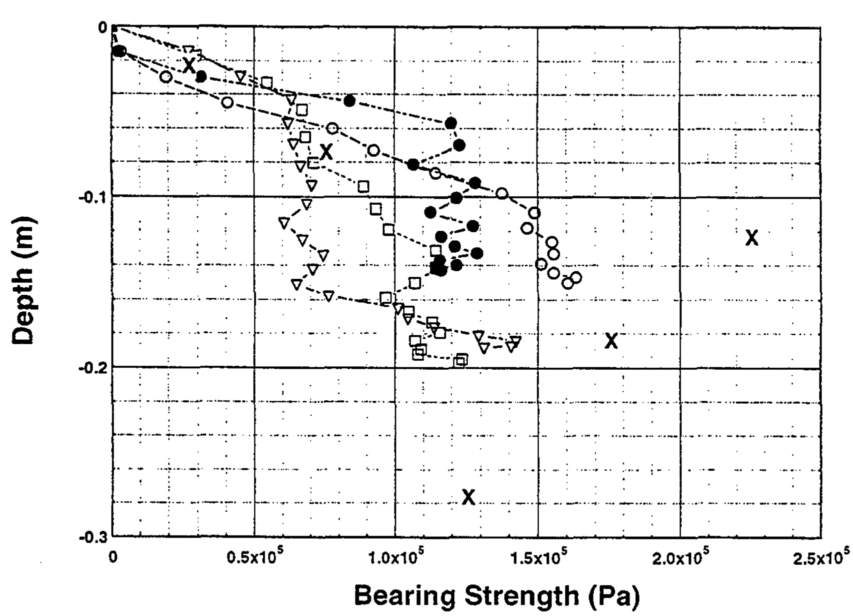

Figure 20. Bearing strength profiles from the ESP versus vane shear results, at station 8. (Vane shear data are indicated by an X; the other symbols are for the different ESP drops).

Appendix A. Data Tables

Table A1. Box core stations (& 1 station where only a video drift was done).

Date	Time (K)	Lat. (S)	Long. (E)	Stat'n No.	Depth (m)	B-Core	G-Core	SDL	T&S	Video
5/8/96	1300	16 46.800	145 47.395	2	7 to 8.5	X	X	X	X	X
	1434	16 48.688	145 46.000	1	7.5	X	X	X	X	X
	1608	16 42.900	145 49.806	3	25	X	X	X	X	X
6/8/96	1055	16 50.484	145 56.626	6	23	X	X		X	X
	1245	16 49.011	145 57.693	7^	33	X	X		X	X
	1318	16 46.905	145 58.223	8^	40	X		X	X	X
7/8/96	0900	16 50.1	146 10.0	11	42	X	X		X	X
	1244	16 40.004	146 03.197	12	27	X		X	X	X
	1405	16 36.301	146 03.298	13	35	X		X	X	
8/8/96	1049	16 45.496	146 07.873	15	50	X	X	X	X	X
	1247	16 45.303	146 05.166	9	43	X		X	X	X
	1421	16 50.316	146 3.890	17	36	X	X	X	X	X
14/8/96	1145	16 41.599	145 54.588	4^	40	X		X	X	X
	1256	16 44.294	146 00.411	5^	50	X		X	X	X
15/8/96	1538	16 51.204	145 53.982	G40^	9					X

^ See stations 1, 2, 4, 5, 7, 8 and G40 in Table A2 also.

Notes for Table A1.
The station positions were GPS antenna's above A.M. Brolga's bridge. In the table, Depth = water depth; B-Core = Box-Core; G-Core = 5 inch diameter gravity core; SDL = Submersible Data Logger for Temperature and Salinity profiles; T&S = sea-surface temperature and salinity; Video = seabed video.

Table A2. Grab, Dredge and ESP stations occupied by A.M. Brolga.

Date	Time(K)	Lat.(S)	Long.(E)	Stn. #	Depth (m)	Grab	NZ ESP	Dredge
12/8/96	1032	16 44.564	145 42.478	G2	10	X	X	
	1045	16 44.4	145 40.9	G1	6			X
	1150	16 42.127	145 39.368	G4	10	X	X	
	1200	16 43.3	145 40.2	G3	6			X
	1254	16 38.133	145 34.569	G8	10	X	X	
	1348	16 40.196	145 35.987	G10	10	X	X	
	1409	16 40.658	145 36.481	G6	10.5	X	X	
	1427	16 41.272	145 37.281	G11	10.2	X	X	
	1449	16 41.827	145 38.359	G5	10	X	X	
13/8/96	0936	16 46.986	145 55.089	9606E	30	X		
	0959	16 48.694	145 55.060	9606S	29	X		
	1015	16 48.991	145 57.711	7	35		X	
	1035	16 46.813	145 58.186	8	35		X	
	1057	16 47.288	145 56.702	9607S	35	X		
	1117	16 45.479	145 55.766	9607E	36	X		
	1235	16 40.601	145 53.483	9601S	38	X	X	
	1255	16 38.773	145 52.195	9601E	33	X		
	1332	16 42.9	145 49.8	9602E	27	X	X	
		16 44.7	145 50.9	9602S	27	X		
	1421	16 46.490	145 50.393	9603S	20	X		
	1438	16 45.158	145 48.731	9603E	20	X		
	1456	16 46.793	145 47.366	2	13		X	

Table A2 continues over page

Table A2 Continued

	1520	16 48.566	145 46.025	1	11		X	
	1539	16 49.002	145.47.60 3	9604E	10.2	X		
	1601	16 47.907	145 50.189	9605E	21	X		
	1620	16 48.988	145 51.890	9605S	14	X		
14/8/96	1145	16 41.599	145 54.588	4	40		X	
	1256	16 44.294	146 00.411	5	50		X	
15/8/96	0756	16 40.591	145 53.507	9601	50		X	
	1016	16 24.255	146 00.833	G31	30	X	X	
	1028	16 25.003	146 01.305	G32	31	X	X	
	1055	16 27.555	146 03.107	G33	48	X	X	
	1125	16 30.005	146 04.806	G34	54	X	X	
	1153	16 32.257	146 06.296	G35	46	X	X	
	1213	16 33.390	146 07.201	G36	50	X	X	
	1236	16 34.753	146 08.066	G37	57	X		
	1249	16 35.701	146 08.450	G38	40	X	X	
	1308	16 37.503	146 08.602	G39	25	X	X	
	1538	16 51.204	145 53.982	G40	9	X	X	
	1604	16 51.543	145 53.440	G41	7.5	X		
	1614	16 50.794	145 53.144	G42	9	X		

Note: Site 9602E is at the same position as Site 3.

Table A3. Grab stations occupied by A.M. Bermagui.

Date	Time(K)	Lat.(S)	Long.(E)	Depth (m)	Station No.
5/8/96	1335	16 55.41	145 56.52	10	G4B (1&2)
	1406	16 59.01	145 54.39	8.6	G36K
	1434	17 00.42	145 54.20	10.1	G37K
	1500	17 02.19	145 53.69	8.9	G38K
	1515	17 03.51	145 53.93	9	G39K
	1525	17 04.81	145 55.01	8.2	G40K
	1535	17 05.85	145 55.98	7.7	G41K
	1602	17 05.90	145 57.20	14.5	G11K
14/8/96		16 52.2	146 04.5	38	9608E
		16 41.8	146 16.8	56	B1
		16 43.7	146 17.6	50	B2
		16 45.6	146 18.3	39	B3
		16 47.3	146 21.0	56	B4
		16 48.9	146 23.6	53	B5
		16 49.2	146 19.3	36	B6
		16 49.4	146 15.0	55	B7

Table A4. Sidescan Sonar Tracks.

A. M. Brolga

(a) 7/8/96: Short tracks over stations 11 and 13.

(b) 12/8/96, 0938 to 0953K, 16 43.057S, 145 53.260E to 16 43.938S, 145 52.689E; Seas too rough for useful data.

(c) 14/8/96, along line of stations 6, 7 and 8: 0923K, 16 51.529S, 145 53.309E; to 0925K, 16 51.497S, 145 53.419E; to 16 51.082S, 145 56.597E; to 1038K, 16 48.931S, 145 57.722E; to 1106K, 16 46.824S, 145 58.204E.

(d) 14/8/96, along line of stations 4 and 5: 1338K, 16 44.414S, 146 00.665E; to 1502K, 16 41.600S, 145 54.90E; to 1511K, 16 41.777S, 145 53.939E.

A.M. Bermagui

(a) Track seaward from middle of lagoon on north side of Arlington Reef 1606K, 16 39.740S, 146 03.417E; to 1850K, 16 32.8S, 146 09.2E; then SE to approximately 16 36.00 S, 146 12.0 E. There was a gap in the first leg over the shallow area near 16 37.4S, 146 05.0E.

(b) 12/8/96: Track to SE from end of the leads of Cairns' entrance channel: 0802K,16 46.3S, 145 51.9E; to 1023K, 16 51.9S, 146 03.3E. Track NW, heading for channel between Green Is. And Arlington Reef: 1153K, 16 50.1S, 146 10.0E; to 1243K, 16 46.907S, 146 04.443E.

(c) 14/8/96: Tracks to the east of Grafton Passage: 1535K, 16 41.682S 146 16.682E; to 1619K, 16 45.695S, 146 18.460E; to 1723K, 16 48.910S, 146 23.623E; 1819K, 16 49.230S, 146 19.780E; to 1945K, 16 50.111S, 146 09.891E.

Table A5. Peak Undrained Shear Strength (kPa), from vane-shear measurements on box cores.

Site ⇒ Depth (m) ⇓	1	2	3	4	5	6	7	8	9	11	12	13	15	17
0.0265	0.92	4.6	1.2	3.1	3.1	0.92	1.2	2.4	1.2	0.61	0.92	1.2	1.5	3.1
0.0755	2.4	6.1	2.8	7.6	6.1	0.92	8.6	7.3	1.2	4.3	4.0	9.2	3.4	4.9
0.1255	3.4	6.1	3.7	12.2	14.7	2.4	15.3	27.5	3.7	6.1	9.8	12.2	4.6	5.5
0.1505											9.2			
0.1755	5.5	7.6	5.5	13.8	12.2	0.61		18.3	6.1	6.7		15.3	2.4	7.6
0.2255	3.7	9.8	1.2		14.7	3.1		12.2	5.5	5.5		15.3	3.7	6.1
0.2755	6.1	6.1				3.1			7.3	7.6		9.2	4.9	4.3
0.3005												6.1		
0.3255	6.1	15.3				3.1			3.1				4.3	1.8
0.3505										7.9				
0.3755	12.2	21.4				1.8				10.4			3.7	8.9
0.4255		18.3				2.4							4.6	9.5
0.4755		12.2												

Table A6. Sensitivities from vane-shear measurements on box cores.

Site⇒ Depth (m)⇓	1	2	3	4	5	6	7	8	9	11	12	13	15	17
0.0265	1.5		4	2	1	1.5	1	1	1	1	1	1.3	1.25	2.5
0.0755	1.3	1.1	9	5	2	1.5	1		1	3.5	1.6	7.5	2.75	4
0.1255	1.85	1.25	1.5	4	4.8	1.3	2.5	4.5	3	5	2.5	13.3	2.5	6
0.1505											1.9			
0.1755	2.6	1.25	4.5	3	4			6	5	5.5		6.25	2	6.25
0.2255	2	1.7			3.2	1.7		2	4.5	2.25		6.25	3	5
0.2755	2	2				1.7			4	3.1		4.3	2.7	3.5
0.3005												2.5		
0.3255	2	3.3				1.7			2.5				2.8	2
0.3505										2.6				
0.3755	1.7	2.3				1.5				3.4			2.4	5.8
0.4255		2.4				1.3							2.5	3.1
0.4755		2												

Table A7. Peak Undrained Shear Strength, Su (kPa), from Averages of Pocket Penetrometer Values

Station	1	2	3	4	5	6	7	8	9	12	13	15	17
Su (kPa)	4.1	0.20	3.1	9.0	13.8	2.5	1.3	15.0	3.5	0	2.0	0	3.8
Range (kPa)	0 to 9.0	0.2	0.5 to 5	7.9 to 10.2	12.5 to 15	2.5	0 to 3	5 to 25	0 to 7	0	1 to 3	0	3 to 4

Table A8. Densities, Porosities and Carbonate %s, from Box Cores

station no.	Depth (m)	field bulk density	Grain density	Porosity	% carb	lab bulk density
S1-1	0.03	1.427	2.35	0.64	16.6	1.38
S1-2	0.105	1.413	2.43	0.62	19.4	1.42
S1-3	0.194	1.453	2.49	0.62	19.1	1.43
S1-4	0.28	1.566	2.55	0.59	17.3	1.51
S1-5	0.39	1.632	2.47	0.56	15.9	1.52
S2-1	0.055	1.369	2.28	0.68	20.1	1.3
S2-2	0.17	1.414	2.69	0.65	23.2	1.39
S2-3	0.26	1.652	2.41	0.64	21.4	1.39
S2-4	0.365	1.577	2.34	0.59	23.0	1.48
S2-5	0.46	1.592	2.43	0.58	24.3	1.48
S3-1	0.03	1.595	2.60	0.58	43.2	1.51
S3-2	0.11	1.678	2.34	0.50	19.9	1.58
S3-3	0.185	1.716	2.41	0.53		1.56
S3-3 (rpt)	0.185		2.58	0.55	49.4	1.56
S3-4	0.255	1.581	2.43	0.57	45.6	1.51
S4-1	0.05	1.691	2.65	0.55	55.2	
S4-2	0.13	1.723	2.54	0.48	54.5	
S4-3	0.21	1.828	2.53	0.51	50.9	
S5-1	0.04	1.896	2.64	0.50	24.7	
S5-2	0.11	1.901	2.61	0.46	26.0	
S5-3	0.18	1.819	2.71	0.52	34.8	
S5-4	0.26	1.713	2.52	0.59	42.2	
S5-5	0.32	1.943	2.67	0.45	16.0	
st6-1	0.055	1.447	2.33	0.73	23.1	1.26
st6-2	0.165	1.373	2.37	0.67	20.2	1.26
st6-3	0.255	1.431	2.37	0.60	20.3	1.47
st6-4	0.4	1.367	2.44	0.70	22.4	1.31
st6-5	0.46	1.431	2.19	0.66	22.7	1.32
S7-1	0.04	1.63	2.67	0.64	71.7	
S7-2	0.105	1.52	2.59	0.52	58.4	
S7-3	0.155	1.65	2.60	0.54	67.3	
S8-1	0.03	1.59	2.59	0.58	83.0	
S8-2	0.11	1.63	2.61	0.54	76.0	
S8-3	0.17	1.58	2.62	0.55	76.8	
S8-4	0.25	1.53	2.62	0.59	72.7	
st9-1	0.04	1.731	2.47	0.56	57.5	1.53
st9-2	0.125	1.693	2.62	0.57	55.3	1.54
st.9-3	0.215	1.738	2.35	0.54	58.4	1.55
st9-4	0.285	1.738	2.51	0.53	59.3	1.58
st9-5	0.385	1.742	2.52	0.55	58.1	1.58
st11-1	0.05	1.669	2.58	0.55	67.6	1.57
st11-2	0.13	1.672	2.53	0.54	67.7	1.6
st11-3	0.2	1.727	2.39	0.53	70.4	1.58
st11-4	0.28	1.718	2.32	0.51	68.2	1.56
st11-5	0.345	1.672	2.53	0.55	67.8	1.57
st12-1	0.04	1.581	2.58	0.64	77.8	1.41
st12-1(rpt)	0.04		2.55	0.66	79.0	1.41
st12-2	0.135	1.791	2.44	0.52	80.1	1.59
S13-1	0.05	1.74	2.619	0.573	72.9415	
S13-2	0.12	1.75	2.686	0.587	72.8859	
S13-3	0.19	1.69	2.635	0.572	72.3306	
S13-4	0.255	1.69	2.662	0.581	72.0758	
st15-1	0.045	1.614	2.36	0.57	60.5	1.52
st15-2	0.12	1.669	2.60	0.57	57.6	1.51
st15-3	0.215	1.576	2.67	0.59	64.7	1.52
st15-4	0.31	1.669	2.75	0.57	63.4	1.55
st15-5	0.375	1.691	2.54	0.56	58.7	1.54
st17-1	0.04	1.691	2.13	0.49		1.61
st17-1 (rpt)	0.04		1.98	0.47	51.2	1.61
st17-2	0.115	1.691	2.42	0.53		1.54
st17-2 (rpt)	0.115		2.44	0.54	52.0	1.54
st17-3	0.22	1.709	2.46	0.54	53.7	1.59
st17-4	0.3	1.731	2.96	0.57	54.7	1.56
st 17-5	0.395	1.731	2.46	0.52	50.9	1.56

S2-3 means: Station 2, 3rd depth down in box core.

Table A9. Densities, Porosities and Carbonite %s from muddier surface samples.

Station	Lab Bulk density	Grain density	Porosity	% carb
G1	1.37	2.51	0.66	41
G2	1.39	2.7	0.66	24.7
G2 (rpt)	1.18	2.32	0.77	12.4
G3	1.46	2.52	0.62	40.3
G4B	1.49	2.51	0.57	27.9
G4B (rpt)	1.56	2.54	0.54	24.6
G5	1.48	2.63	0.61	20.9
G6	1.51	2.53	0.58	26.6
G 8	1.26	2.43	0.73	12.7
G 10	1.41	2.57	0.63	17.7
G 11	1.33	2.52	0.69	16.4
9602S	1.48	2.84	0.62	39
9603S	1.43	2.51	0.63	30.4
9603E	1.4	2.46	0.65	28.6
9604E	1.41	2.47	0.64	16.6
9605S	1.31	2.28	0.67	18.1
9605E	1.29	2.74	0.74	20
9606E	1.4	2.37	0.61	49.6
9606W	1.41	2.47	0.65	46.9
9607S	1.52	2.53	0.6	70.2
9608S	1.58	2.45	0.53	
9608S(rpt)	1.58	2.6	0.55	55
G40	1.62	2.51	0.47	
G40(rpt)	1.62	2.51	0.47	9.7
G42	1.47	2.52	0.59	12.3
G4B-1	1.57	2.5	0.52	9.5
G4B-2	1.57	2.44	0.52	
G4B-2(rpt)	1.57	2.48	0.52	7.4
G36K	1.72	2.41	0.42	5.3
G37K	1.22	2.18	0.75	8.9
G38K	1.3	2.26	0.69	8.9
G39K	1.4	2.44	0.63	8
G40K	1.24	2.16	0.75	
G41K	1.42	2.42	0.62	5.3
G41K(rpt)	1.27	2.37	0.72	13

Table A10. Coarser Box Core Samples.

- Gravel, Sand and Mud %s & Carbonate %s in mud and sand (sizes by sieving).

Station	Depth (m)	% mud	% sand	% gravel	%carb (mud)	%carb (sand)
S4-1	0.05	19.4	69.3	11.4	44.0	51.0
S4-2	0.125	25.7	64.8	9.6	44.0	52.0
S4-3	0.205	23.2	70.8	5.9	44.0	49.0
S5-1	0.04	16.5	79.2	4.3	42.0	17.0
S5-2	0.11	15.5	80.3	4.2	42.0	19.0
S5-3	0.18	10.1	85.3	4.7	37.0	31.0
S5-4	0.255	14.8	75.9	9.2	38.0	36.0
S5-5	0.315	22.4	73.1	4.5	22.0	9.0
S7-1	0.04	25.0	47.6	27.4	23	81.0
S7-2	0.105	47.8	27.5	24.7	24.0	81.0
S7-3	0.155	36.5	26.6	37.0	25.0	80.0
S8-1	0.03	19.4	47.2	33.4	34.0	91.0
S8-2	0.11	34.3	41.0	24.7	42.0	90.0
S8-3	0.17	31.2	38.6	30.2	38.0	90.0
S8-4	0.25	34.4	44.2	21.4	36.0	88.0
S12-1	0.04	87.83	10.61	1.56	77	92
S13-1	0.05	55.2	44.7	0.1	68.0	79.0
S13-2	0.12	57.6	41.3	1.0	68.0	79.0
S13-3	0.19	61.1	38.7	0.2	68.0	79.0
S13-4	0.255	60.0	39.6	0.4	68.0	78.0

Table A11. Coarser Surface Samples.
Grain Density, Porosity, Carbonate % & Carbonate %s in mud and sand, & Gravel, Sand and Mud %s (sizes by sieving)

Sample	Grain density	Porosity	% Carbonate	% mud	% sand	% gravel	%carb (mud)	%carb (sand)
9601	2.575	0.51	48.7939	11.5	79.0	9.6	46.0	43.0
9601E	2.517	0.555	56.7551	13.0	83.4	3.7	43.0	57.0
9607	2.637	0.623	72.4436	27.4	45.4	27.2	26.0	84.0
9607E	2.453	0.625	71.8866	33.2	47.5	19.3	31.0	89.0
B1	2.728	0.647	92.6523	14.1	34.5	51.4	70.0	91.0
B2	2.682	0.617	91.7308	20.2	43.0	36.8	74.0	93.0
B3	2.731	0.637	95.4011	5.4	40.2	54.4	67.0	93.0
B4			97.8819	0.8	20.2	79.0	~35 ?	92.0
B5	2.696	0.56	96.5446	6.1	27.0	66.9	70.0	94.0
B6	2.699	0.608	92.3872	3.7	91.3	5.0	67.0	93.0
B7	2.659	0.611	74.7556	44.5	53.7	1.8	65.0	82.0
G31	2.679	0.582	89.7799	9.2	90.1	0.8	67.0	92.0
G32	2.764	0.517	94.8252	1.0	79.1	19.9	54.0	94.0
G33	2.674	0.62	79.7376	26.1	72.9	1.1	67.0	84.0
G34	2.690	0.571	87.3698	9.6	86.1	4.3	67.0	89.0
G35	2.731	0.545	90.4513	12.2	73.8	14.1	64.0	93.0
G36	2.520	0.578	92.3378	6.9	71.2	21.9	61.0	93.0
G37	2.670	0.607	83.0476	14.9	84.7	0.5	60.0	87.0
G38	2.514	0.576	87.1042	3.5	95.4	1.2	58.0	88.0
G39	2.545	0.56	91.1887	2.1	87.5	10.4	56.0	91.0
G39 A	2.541	0.556	93.3103	2.6	80.4	17.1	58.0	93.0
41 duplicat	2.632	0.468	<10.6184	1.2	98.6	0.2	<12	10.0

Table A12. Gravel/Sand/Mud %s by sieving (Muddier samples)

Surface samples

sample	% gravel	% sand	% mud
G1	2.84	17.05	80.11
G2	5.38	20.09	74.53
G2 (rpt)	0.00	6.79	93.21
G3	2.00	57.98	40.02
G4B	2.27	61.48	36.24
G4B (rpt)	3.72	66.06	30.22
G5	2.64	41.33	56.03
GS5 (rpt)	0.40	42.26	57.34
G6	0.52	42.53	56.95
G 8	0.00	8.43	91.57
G 10	1.45	43.11	55.44
G 11	0.05	7.39	92.55
G40	4.37	74.42	21.22
G42	0.08	42.28	57.65
G11K	0.69	16.40	82.90
G37K	0.00	2.39	97.61
G38K	0.13	8.23	91.63
G39K	0.42	12.04	87.54
G40 K	0.93	2.25	96.81
G41 K	2.02	70.46	27.52
9601S	13.23	75.66	11.11
9602S	1.65	51.65	46.70
9603S	0.63	21.63	77.75
9603 E	0.54	21.38	78.08
9604 E	0.03	8.29	91.68
9605E	0.07	9.86	90.08
9605S	0.20	6.49	93.31
9606E	9.16	28.03	62.82
9606S	9.69	33.76	56.55
9607S	29.38	40.40	30.22
9607E	26.47	41.63	31.91
9608S	2.30	59.64	38.06

Note: S1-2 means Site 1, 2nd deepest sample in core; ST 11-5 means Site 11, 5th deepest sample in core

Core samples

sample	Depth (m)	% gravel	% sand	% mud
S 1-1	0.03	0.73	5.59	93.68
S 1-2	0.105	0.00	17.33	82.67
S 1-3	0.194	0.00	15.64	84.36
S1-4	0.28	1.71	18.79	79.50
ST 1-5	0.39	1.23	14.24	84.53
S 2-1	0.055	0.00	20.25	79.75
S 2-2	0.17	0.00	24.55	75.45
S 2-3	0.26	0.45	18.75	80.80
S 2-4	0.365	0.71	16.13	83.16
S 2-5	0.46	0.37	20.34	79.29
S 3-1	0.03	3.32	68.13	28.55
S3-2	0.11	5.58	64.73	29.68
S 3-3	0.185	5.99	63.42	30.59
S 3-4	0.255	5.47	60.06	34.47
ST 6-1	0.055	0.00	12.10	87.90
ST 6-2	0.165	0.00	9.83	90.17
ST 6-3	0.255	0.50	18.05	81.45
ST 6-4	0.4	0.45	8.39	91.16
ST 6-5	0.46	1.21	8.06	90.73
ST 9-1	0.04	0.51	55.69	43.80
ST 9-2	0.125	0.60	54.42	44.98
st 9-3	0.215	4.12	53.84	42.05
ST 9-4	0.285	1.03	54.71	44.26
ST 9-5	0.385	1.36	56.70	41.94
ST 11-2	0.13	1.45	33.32	65.22
ST 11-3	0.2	0.95	35.53	63.52
ST 11-4	0.28	1.03	32.19	66.78
ST 11-5	0.345	0.75	33.52	65.72
ST 12-1	0.04	0.47	14.16	85.37
ST 12-2	0.135	0.76	13.11	86.12
ST 15-1	0.045	1.52	40.62	57.85
ST 15-2	0.12	1.53	38.97	59.50
ST 15-3	0.215	1.65	46.82	51.52
ST 15-4	0.31	2.66	51.92	45.42
ST 15-5	0.375	4.77	43.59	51.64
ST 17-1	0.04	1.05	68.18	30.77
ST 17-2	0.115	0.83	62.77	36.40
ST 17-3	0.22	1.66	59.17	39.17
ST 17-4	0.3	1.41	65.41	33.18
st 17-5	0.395	1.98	64.32	33.70

Table A13. Gravel, Sand, Silt and Clay %s for muddier box core samples (particle size analyser and sieve samples melded together).

							Mode of
sample	Depth (m)	% gravel	% sand	% silt	% clay	Sed Type	Silt Fraction
S 1-1	0.03	0.73	34.67	62.93	1.68	sandy silt	coarse
S 1-2	0.105	0.00	27.84	70.44	1.73	sandy silt	coarse
S 1-3	0.194	0.00	26.96	71.30	1.73	sandy silt	coarse
S1-4	0.28	1.71	31.17	65.61	1.52	sandy silt	coarse
ST 1-5	0.39	1.23	20.47	75.71	2.58	silt	coarse
S 2-1	0.055	0.00	32.90	65.01	2.09	sandy silt	coarse
S 2-2	0.17	0.00	36.24	60.97	2.79	sandy silt	coarse
S 2-3	0.26	0.45	31.57	65.37	2.61	sandy silt	coarse
S 2-4	0.365	0.71	30.13	67.45	1.69	sandy silt	coarse
S 2-5	0.46	0.37	29.10	68.07	2.44	sandy silt	coarse
S 3-1	0.03	3.32	73.92	22.06	0.70	silty sand	coarse
S3-2	0.11	5.58	68.55	25.02	0.84	silty sand	coarse
S 3-3	0.185	5.99	67.58	25.34	1.09	silty sand	coarse
S 3-4	0.255	5.47	63.50	29.46	1.57	silty sand	coarse
ST 6-1	0.055	0.00	17.55	76.72	5.73	silt	fine
ST 6-2	0.165	0.00	18.13	78.12	3.75	silt	coarse
ST 6-3	0.255	0.50	26.54	70.30	2.66	sandy silt	coarse
ST 6-4	0.4	0.45	13.36	79.31	6.88	silt	fine
ST 6-5	0.46	1.21	15.48	79.56	3.76	silt	coarse
ST 9-1	0.04	0.51	59.48	38.89	1.12	sand/silt	coarse
ST 9-2	0.125	0.60	60.06	38.55	0.79	silty sand	coarse
ST 9-3	0.215	4.12	63.07	32.37	0.44	silty sand	coarse
ST 9-4	0.285	1.03	62.85	34.59	1.53	silty sand	coarse
ST 9-5	0.385	1.36	62.69	35.33	0.62	silty sand	coarse
ST 11-2	0.13	1.45	50.42	47.68	0.44	sand/silt	coarse
ST 11-3	0.2	0.95	50.71	47.99	0.34	sand/silt	coarse
ST 11-4	0.28	1.03	42.67	55.88	0.41	sand/silt	coarse
ST 11-5	0.345	0.75	45.86	52.94	0.45	sand/silt	coarse
ST 12-1	0.04	0.47	26.03	71.54	1.96	sandy silt	fine
ST 12-2	0.135	0.76	22.98	74.92	1.33	silt	coarse
ST 15-1	0.045	1.52	49.74	48.01	0.72	sand/silt	coarse
ST 15-2	0.12	1.53	50.55	46.62	1.30	sand/silt	coarse
ST 15-3	0.215	1.65	53.17	44.58	0.60	sand/silt	coarse
ST 15-4	0.31	2.66	58.73	37.81	0.80	sand/silt	coarse
ST 15-5	0.375	4.77	51.16	43.39	0.68	sand/silt	coarse
ST 17-1	0.04	1.05	73.82	24.72	0.40	silty sand	coarse
ST 17-2	0.115	0.83	71.12	27.55	0.51	silty sand	coarse
ST 17-3	0.22	1.66	64.55	32.91	0.87	silty sand	coarse
ST 17-4	0.3	1.41	70.52	27.63	0.45	silty sand	coarse
st 17-5	0.395	1.98	72.42	24.86	0.74	silty sand	coarse

Table A 14. Gravel, Sand, Silt and Clay %s for muddier surface samples (particle size analyser and sieve samples melded together).

sample	% gravel	% sand	% silt	% clay	Sed Type	Mode of Silt Fraction
G 1	2.84	24.59	69.90	2.67	sandy silt	coarse
G 1(rpt)	5.38	28.18	64.21	2.24	sandy silt	coarse
G2	0.00	12.01	81.97	6.02	silt	fine
G 3	2.00	60.80	35.81	1.40	silty sand	fine
G4B	2.27	64.14	31.90	1.68	silty sand	coarse
G4B (rpt)	3.72	68.35	26.62	1.31	silty sand	coarse
G5	2.64	47.70	48.05	1.61	silt/sand	coarse
G5 (rpt)	0.40	51.23	47.46	0.90	sand/silt	coarse
G 6	0.52	52.12	46.00	1.37	sand/silt	coarse
G 8	0.00	19.65	77.14	3.22	silt	coarse
G 10	1.45	57.69	39.84	1.03	sand/silt	coarse
G 11	0.05	26.64	71.86	1.44	sandy silt	coarse
G40	4.37	76.46	17.40	1.78	sand	coarse
G42	0.08	51.97	45.82	2.12	sand/silt	coarse
G11K	0.69	20.91	73.80	4.59	silt	fine
G37K	0.00	8.01	89.86	2.14	silt	fine
G38K	0.13	14.54	82.97	2.35	silt	coarse
G39K	0.42	21.42	76.43	1.72	silt	coarse
G40 K	0.93	7.40	86.49	5.17	silt	coarse
G41 K	2.02	72.70	23.80	1.48	silty sand	fine
9602S	1.65	59.53	36.99	1.84	silty sand	coarse
9603S	0.63	30.82	65.69	2.85	sandy silt	coarse
9603 E	0.54	29.96	66.79	2.69	sandy silt	coarse
9604 E	0.03	17.51	80.29	2.17	silt	coarse
9605E	0.07	24.41	70.61	4.92	silt	coarse
9605S	0.20	23.58	73.46	2.76	silt	coarse
9606E	9.16	32.91	55.25	2.68	sandy silt	coarse
9606S	9.69	39.90	47.53	2.88	sand/silt	coarse
9607S	29.38	41.42	27.50	1.70	si. shl. Sa	fine
9608 S	2.30	64.42	31.95	1.33	silty sand	coarse

Table A15. Compressional sound speeds from sediments in box cores.

Sensor spacing (m) = 0.087

Station No.	Depth (m)	Sound Speed (m/s)
1	0.040	1497.42
1	0.100	1492.28
1	0.221	1497.42
1	0.261	1570.40
2	0.040	1510.42
2	0.081	1500.00
2	0.141	1497.42
2	0.221	1573.24
2	0.341	1638.42
2	0.421	1608.13
3	0.040	1545.29
3	0.100	1550.80
3	0.221	1553.57
3	0.261	1548.04
4	0.040	1843.22
4	0.081	1660.31
4	0.141	1629.21
4	0.181	1635.34
4	0.181	1629.21
5	0.081	1827.73
5	0.081	1823.90
5	0.221	1761.13
5	0.301	1632.27
6	0.040	1492.28
6	0.081	1507.80
6	0.100	1487.18
6	0.221	1497.42
6	0.341	1489.73
7	0.040	1550.80
7	0.100	1617.10
7	0.181	1635.34
8	0.040	1523.64
8	0.100	1531.69
8	0.181	1500.00
8	0.261	1534.39

Station No.	Depth (m)	Sound Speed (m/s)
9	0.040	1518.32
9	0.100	1526.32
9	0.221	1534.39
9	0.341	1537.10
9	0.421	1515.68
11	0.040	1507.80
11	0.100	1513.04
11	0.221	1510.42
11	0.341	1531.69
11	0.421	1542.55
12	0.040	1450.00
12	0.081	1467.12
12	0.141	1497.42
13	0.040	1497.42
13	0.100	1542.55
13	0.221	1542.55
13	0.301	1537.10
15	0.040	1545.29
15	0.100	1545.29
15	0.221	1523.64
15	0.341	1518.32
17	0.040	1526.32
17	0.100	1537.10
17	0.221	1570.40
17	0.341	1542.55
17	0.421	1539.82

Table A16. Acoustic Measurements on 5" gravity cores from J. Dunlop.

Station No.	Depth (m)	Freq. (kHz)	Sound Speed Ratio	Atten- uation (dB/m)	Shear Velocity (m/s)	Poros- ity	g 10^{-12}	k
15	~0.75	46.4	0.987	--	26	0.61	2.69	0.23
		90	0.992	63				
		340	1.080	162				
		1050	1.120	191				
17	~0.24	90	1.007	71	32	0.56	2.54	0.26
		340	1.029	162				
		1050	1.032	200				
17	~0.75	46.4	1.038	--	30	0.52	1.09	1.23
		90	1.078	141				
		340	1.115	246				
		1050	1.122	316				
17	~0.75	90	1.076	117	30	0.47	1.36	0.68
	(dup)	340	1.13	200				
		1050	1.19	251				

Table A17. Comparison of Porosities, and of Sound Speed Ratios at 50 kHz

Site No. (depth)	Vel. Ratio (Dunlop)	Vel. Ratio (Box core)	Porosity (Dunlop)	Porosity (Box core)
15 (~0.75 m)	0.984 ± 0.003	0.990 ± 0.025	0.61 ± 0.01	0.56 ± 0.01
17 (~0.24 m)	1.000 ± 0.003	1.024 ± 0.025	0.56 ± 0.01	0.54 ± 0.01
17 (~0.75 m)	1.050 ± 0.003	1.004 ± 0.025	0.52 ± 0.01	0.52 ± 0.01
17 (~0.75 m) repeat	1.051 ± 0.003	1.004 ± 0.025	0.47 ± 0.01	0.52 ± 0.01

Table A18. On board descriptions of box core samples.

Date	Station No.	Core Length (m)	Description
5 August 1996	2	0.51	uniform dark grey mud
	1	0.45	uniform dark grey mud
	3	0.30	some animal holes on surface, which is yellowish mud; shells in mud in lower half
6 August 1996	6	0.53	some animal grooves and holes on surface; mud was yellowish near the surface, then uniform grey deeper
	7	0.22	yellow and shelly in top 0.12 m, then grey, lower
	8	0.31	small marine growth on surface; more yellow and sandy towards top; tends to more dark grey mud, lower
7 August 1996	11	0.42	surface was yellowish grey with small holes
	12	0.17	uniform yellowish pale grey; very stiff like compacted clay, at bottom
	13	0.34	uniform light grey, maybe slightly sandier in top 30 mm
8	15	0.44	uniform pale grey, but yellower and slightly sandier at top
	9	0.41	as for station 15
	17	0.55	similar to stations 9 and 15, but definitely yellowish in top 60 or 70 mm
14 August 1996	4	0.24	approximately 140 mm of shelly sand above approximately 100 mm of grey mud
	5	0.35	much life apparent on surface; core a uniform shelly sand with trace of dark brown mud at bottom; more of last outside box, on spade

Appendix B. The Electronic Sediment Strength Probe (ESP) (adapted from Mulhearn et al., 1998)

The Electronic Sediment Strength Probe (ESP) is based on a simple, mechanical penetrometer designed and built at DSE about 15 years ago. The latter was a light spear-shaped device, whose penetration was recorded passively by noting where the mud had lodged in a series of rings around the shaft. The ESP was subsequently designed in response to requirements for more accurate and detailed data. It contains a strain-gauge type accelerometer that has frequency response extending to DC - important in the data analysis described below - and a self-contained digital data recorder. The data recorder is a chipset originally intended for voice recording in consumer electronic gadgets (Clement, 1989). The input signal coupling from the accelerometer, and the output readout signal coupling were both modified from the supplier's application notes to DC-coupling of both.

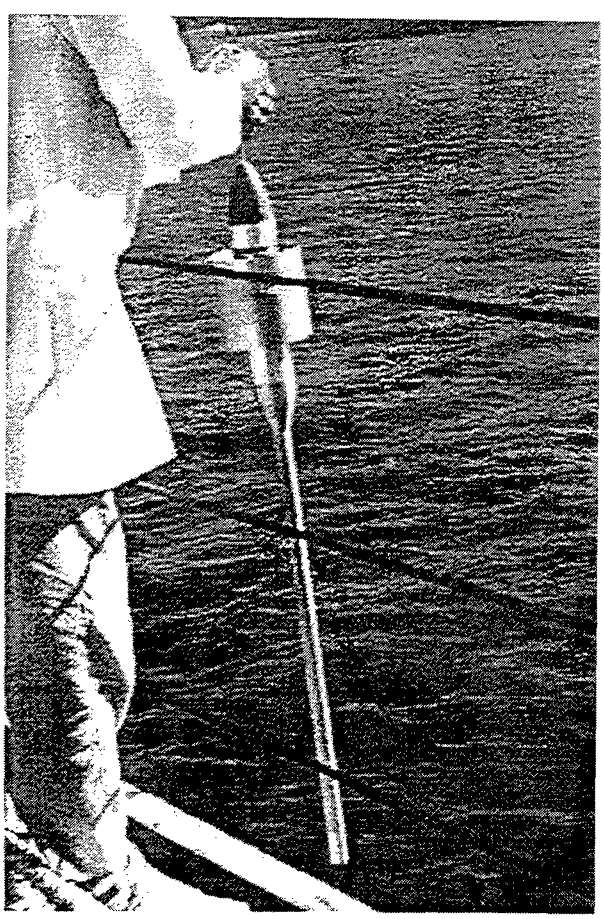

Figure B-1: The ESP

The ESP is shown in Figure B-1. The general mechanical design is apparent from the figure. All of the electronics are contained in the bulbous housing at the top. The earlier penetrometer had been light enough to be easily handled manually. It can be seen that the new penetrometer retains this advantage.

The ESP has a mass of 5.34 kg, a weight in water of 27.17 N, and a terminal velocity of about 3 ms^{-1}. Its thin shaft has a diameter of 33 mm. Its area kinetic energy density is around 30 kJ m^{-2}. The strain rate (conveniently measured as speed in diameters per second) is much higher for the ESP than for a mine. Also, the side adhesion effects (True, 1975) are potentially much greater for the ESP.

Data Acquisition

To use the ESP, the "record" mode is initiated, using either a plug-in control cable at the top or a magnetically-operated switch. There are then 2 ½ minutes of data recording time available. The device is dropped over the side of the ship or boat, with a light tether line attached, and falls freely to the sea floor. The

impact is recorded. Usually there is enough recording time to record several more impacts by lifting the ESP a few metres clear of the sea floor, using a light attached line, and re-releasing. Then the penetrometer is recovered, the playback mode is initiated, and the data is downloaded to a computer for analysis.

Although the recorder on the ESP stores data digitally, it is read out in analogue form. This is accurate enough for the purpose and results in very simple data connections. The analogue signal is applied to a small self-contained analogue-to-digital converter that plugs into the printer port on an IBM-compatible PC.

Data Analysis
A typical example of a complete downloaded data set is shown in Figure B-2. The computer software allows selection and "zooming-in" to the small subsets (typically 1-2 s in duration) that contain the actual sediment impact and some 1 s or so of data following the impact.

The velocity and position signals are recovered through integrating the accelerometer signal twice, giving the acceleration as a function of position as a result.

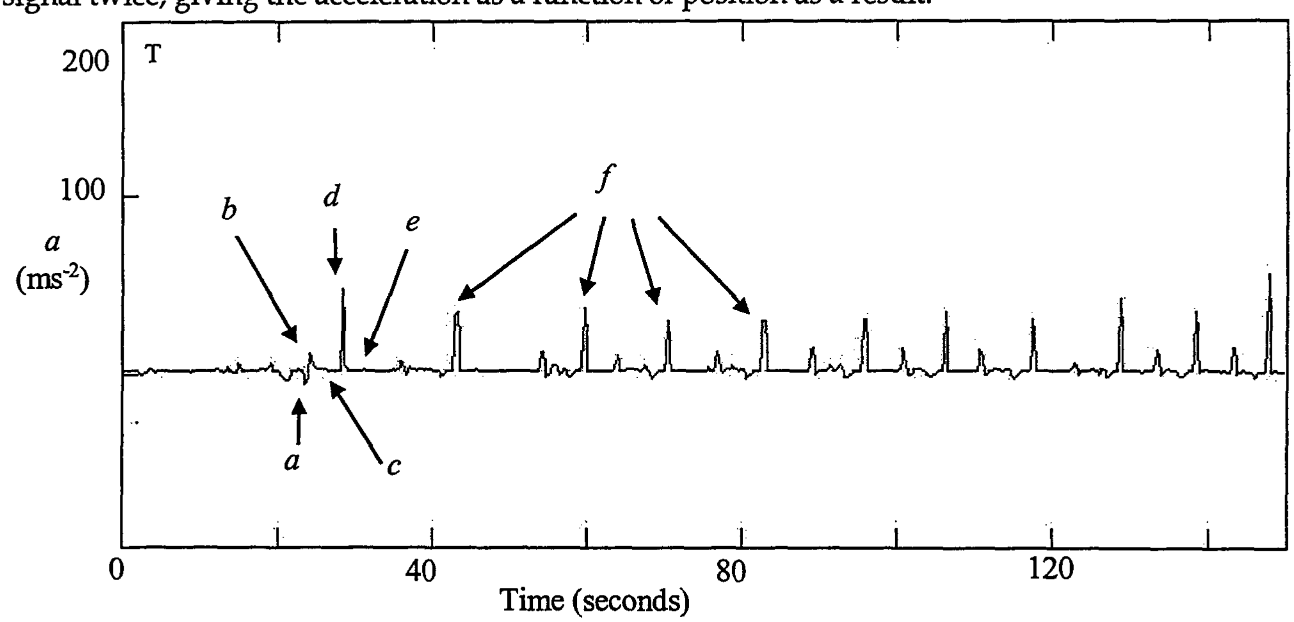

Figure B-2: A Typical ESP Data Record

A typical ESP data record shows features that can be recognised in most records:

a) a negative blip representing the initial launching of the probe
b) a positive blip as the probe hits the water
c) a smooth section where the probe falls through the water at terminal velocity
d) the impact into the sediment
e) a smooth section when the probe is at rest in the sediment
f) subsequent impacts into the sediment

The acceleration is just the total force acting on the probe, divided by its effective mass. The total force is the vector sum of the weight, the buoyancy force, the hydrodynamic drag, and the force required to advance the probe through the sediment. All these forces, with the exception of the sediment force, can be either calculated or calibrated. Therefore the sediment force is the only unknown and can be estimated, and the sediment strength profile can then be deduced.

Appendix C. Sea Floor Videos

Video film footage was obtained, with the ship drifting, as described in Section 2.1, at each of the box core stations, except station 13. Short descriptions of the seabed at these stations are listed below.

Station 1. There were many small mounds (probably about 20 to 30 mm high) and burrows in the mud at this site. There were no big holes, and no weed or shell pieces.

Station 2. Many mounds and burrows with a fair range of sizes (holes up to 100 mm across) were observed here. The seabed didn't look quite as soft as at station 1, but had a rough but furry appearance. A cloud of fine sediment was kicked up, when the camera frame first struck the bottom. A fish was seen to kick up a dust swirl.

Station 3. Many small holes and mounds were here also. (Holes were up to 120 mm across). Bottom was quite rough at the 20 to 100 mm scale but had low relief. There were occasional pieces of white shell, less than 20 mm wide. The sea floor looked sandy, and there were occasional linear marks in the bottom, perhaps due to dragged cables. A transparent fish, like a black bream, was seen sheltering in a largish crater, and a little white fish was seen to dive down one of the small burrows. It may not have been its own. A large white fish was also seen.

Station 4. The seabed here was quite smooth with some small burrows. There was an occasional hole as wide as 30 mm. There were many pieces of shell, less than 20 mm wide, and isolated small clumps of what appeared to be weed. Later in the video run the bottom became more lumpy, and there were many more "weed" clumps. A large star fish was also observed.

Station 5. Seabed had small scale lumpy low relief. There were some burrows and individual clumps of marine growth scattered about. There appeared to be less weed and shell than at station 4, but the film was out of focus.

Station 6. The muddy sea floor looked much rougher than at previous stations, with many mounds (up to 50 mm high) and burrows (up to 300 mm across). There were also a couple of mounds shaped like volcanoes, about 200 mm high and 400 mm across, which are probably made by Callianassid prawns. Small plumes of sediment were observed being ejected from a few burrows, and clouds of sediment were kicked up when the camera frame struck the seabed.

Station 7. The bottom looked muddy, but quite lumpy in places, with a scattering of rocks and pieces of coral and some weed clumps, which were quite numerous in places. There were some burrows, but less than at stations 1 to 3 and 6. The camera frame ran right into one of the large volcano-like structures. Clouds of sediment were

not kicked up when the camera frame struck the seabed. Bottom properties appeared to be quite variable at this site.

Station 8. Seabed looks quite rough, with low relief of 30 to 50 mm. There appear to be very many small rocks poking up through the sediment surface. There were shell pieces less than 20 mm across, and some tufts of black weed. The sea floor at this site looked much harder and rougher than that at station 7, but some dust was kicked up when the camera frame first struck the bottom. Near the start of the run there were also some ridges. 3 or 4 volcano-like structures were seen at the start of the run, but these became rarer after that. The sediment down the sides of the "volcanoes", at the start of the run, was much paler than that of the surrounding seabed, suggesting that the organisms producing these structures were currently active.

Station 9. There were very many holes (about 20 mm diameter) and mounds at this station. Large clouds of sediment were kicked up at times, when the camera frame struck the bottom. Some weed and clearly visible dead shells seen, and a few larger holes. One "volcano" seen.

Station 11. Sea floor looked muddy here, with many small (~ 20 mm) holes and mounds. No weed or larger holes were seen. The bottom looked smoother than at stations 1 to 3. A cloud of sediment was kicked up when the camera frame first hit the bottom.

Station 12. Visibility was poor at this site, but there appeared to be many burrows. When the camera frame first hit the seabed, the material that was kicked up looked like lots of leaves, swirling about.

Station 15. There were many holes (< 30 mm) and mounds at this site, but in places there appeared to be an underlay of cross-hatched ripple marks. Some holes were approximately 120 mm across. The bottom looked like sticky mud and fine dust was kicked up when the camera frame first struck the seabed. A number of "volcanoes" were seen, and the camera ran into a large one, about 800 mm high and over 1 m wide. A number of small fish were seen, and one small shark.

Station 17. The sea floor here was smooth and the sediment looked coarse. There were only a few holes, up to 100 mm diameter.

Appendix D. ESP deployments, without accompanying vane shear data

ESP deployments obtained without accompanying vane shear measurements were obtained from:
(i) in-shore sites to the north of Cairns,
(ii) one site within the Great Barrier Reef Lagoon, between the coast and Arlington Reef,
(iii) sites along the outer edge of the Reef, and
(iv) one site near Cape Grafton.
See Table A2 for positions.

The ESP drops for the in-shore sites to the north of Cairns are shown in Figures D-1 to D-7. The results for stations G4, G10, G6, G11 and G5 are similar to those at stations 1, 2 and 3 (see Figures 14 to 16), while the bearing strengths at stations G4 and G 8 are significantly lower than those found elsewhere. The reason for these lower values is not apparent from the sediment analyses. The variability at station G5 (see Figure D-7) is larger than that at other in-shore stations.

Station 9601, in the Lagoon, was occupied on two separate days, 13th and 15th August. The results from the first occasion, shown in Figure D-8, revealed that the sea floor at this site was highly variable. Those obtained on the second occasion, shown on Figure D-9, were different again, but more consistent with each other.

The ESP drops along the outer edge of the Reef are shown in Figures D-10 to D-17. The results fall into two groups: those from hard bottoms, with penetrations of only 0.03 to 0.06 m and peak bearing strengths of order 6×10^5 Pa (Sites G31, G32, G38 and G39) ; and those with lower bearing strengths and penetrations of up to 0.12 to 0.18 m (Sites G33, G34, G35, G36). The latter generally gave results which were highly variable, indicating a rapid transition in bottom types at these locations. When the data show penetrations of order 30 mm it is not clear that the ESP, whose shaft has a diameter of 33 mm, has penetrated at all. One would expect some deceleration when the probe tip was of order one shaft diameter above a hard bottom, due to the cushion of water between the tip and the sea bed. With little or no penetration the ESP would fall over immediately after impact, making the results difficult to interpret.

The final ESP deployment was at site G40, near Cape Grafton. Again the results show variability between individual impacts, but, overall, the values are similar to those found at sites 1 to 3, and at most in-shore stations.

The ESP drops at a number of stations achieved very little penetration and the data show a definite peak in bearing strength, with lower bearing strength values below it in the sediment (Figures D-8 to D-10, D-15 and D-16). The values below the peak are probably unreliable. The most likely explanation is that the ESP fell over because its

shaft had such little penetration. Data from some other sites also show definite peaks, but have penetrations of order 0.3 to 0.4 m (Figures D-4, D-6, D-7). In these cases, which were at in-shore sites with sticky mud, the ESP is unlikely to have fallen over, and there appears to have been a stronger layer overlying a weaker.

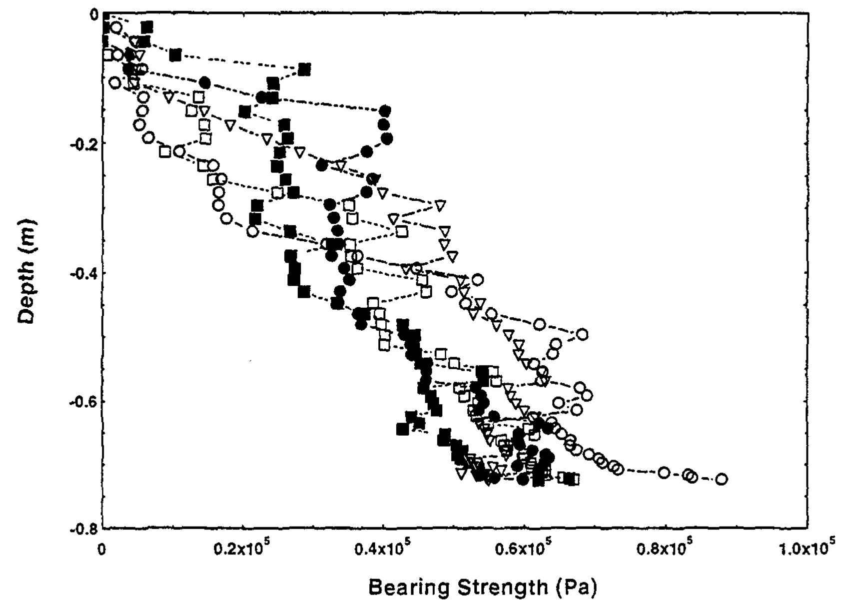

Figure D-1. Bearing strength profiles from multiple ESP drops at station G2.

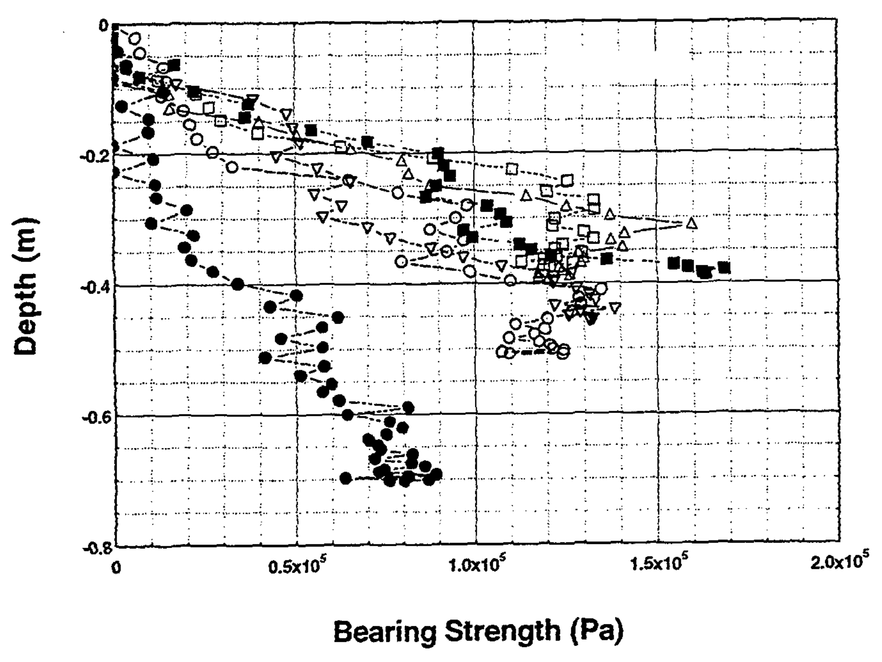

Figure D-2. Bearing strength profiles from multiple ESP drops at station G4.

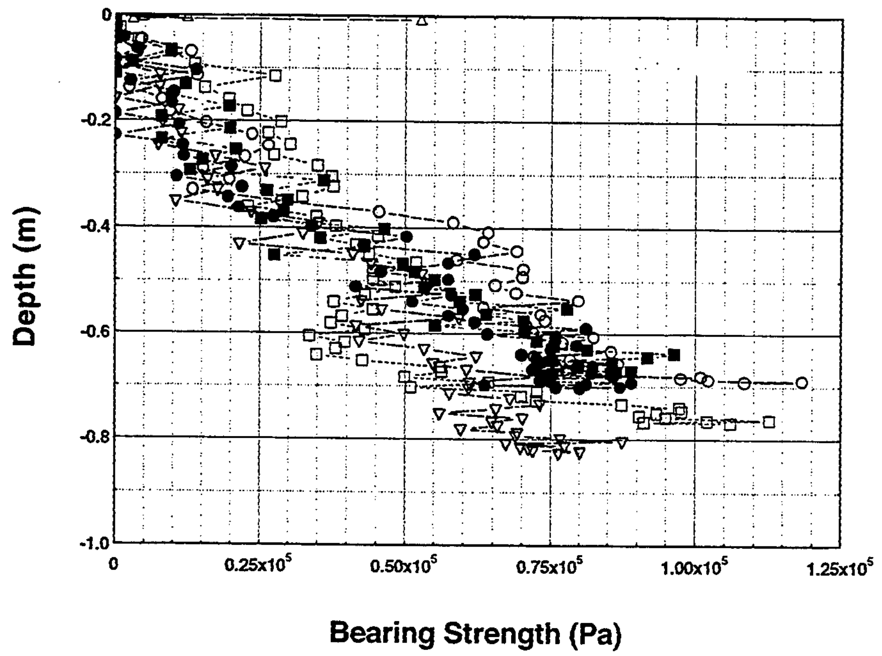

Figure D-3. Bearing strength profiles from multiple ESP drops at station G8.

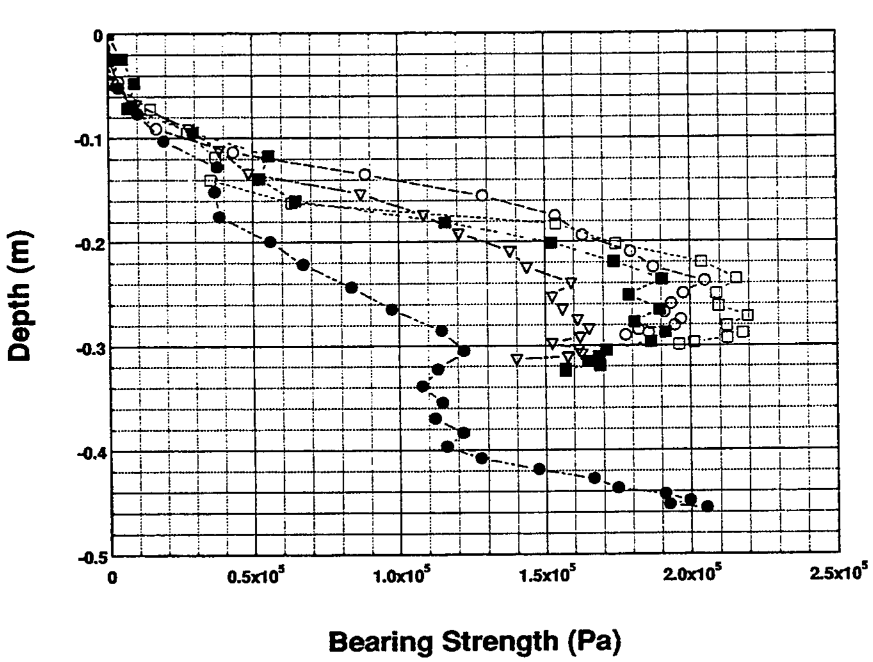

Figure D-4. Bearing strength profiles from multiple ESP drops at station G10.

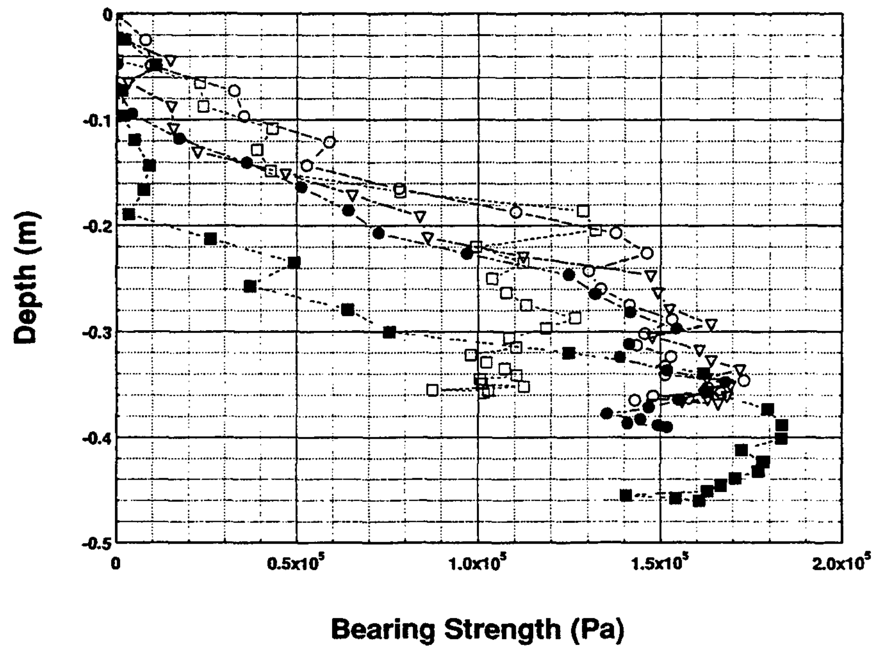

Figure D-5. Bearing strength profiles from multiple ESP drops at station G6.

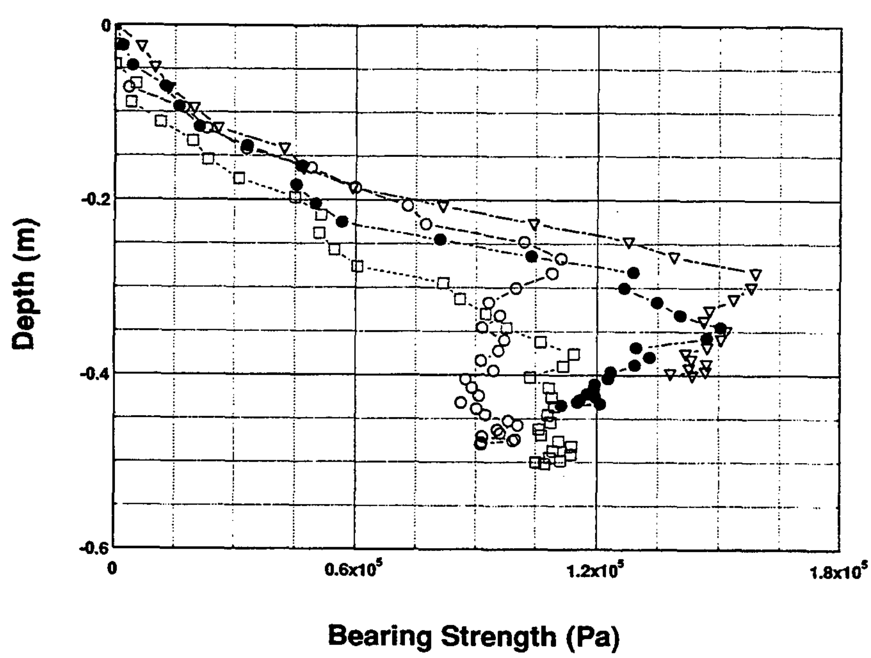

Figure D-6. Bearing strength profiles from multiple ESP drops at station G11.

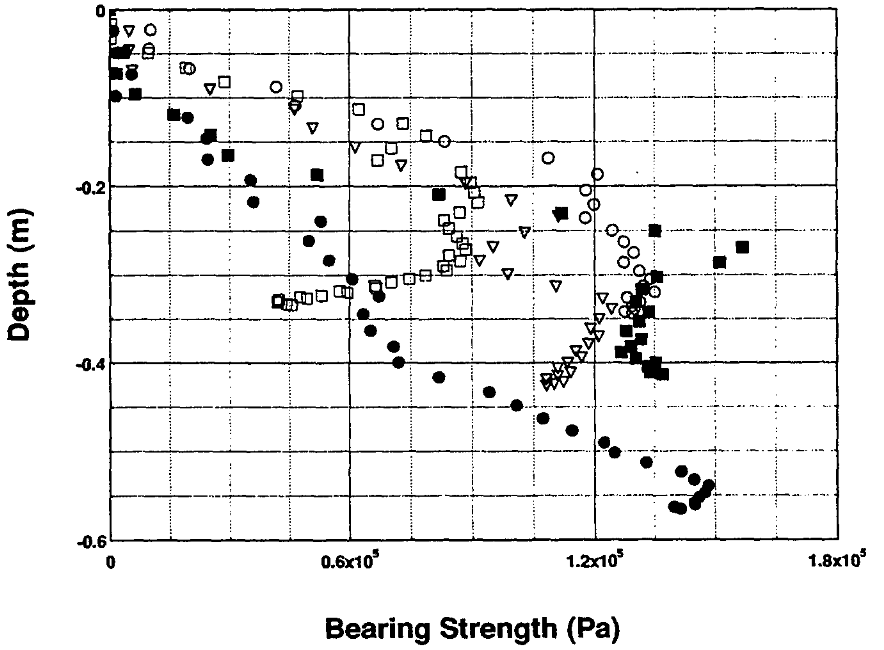

Figure D-7. Bearing strength profiles from multiple ESP drops at station G5.

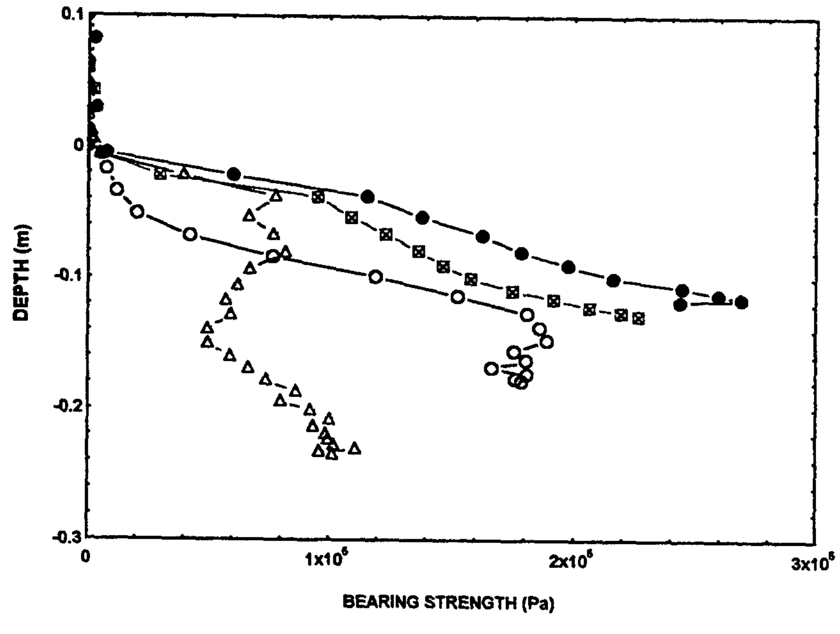

Figure D-8. Bearing strength profiles from multiple ESP drops at station 9601, on 13 August 1996.

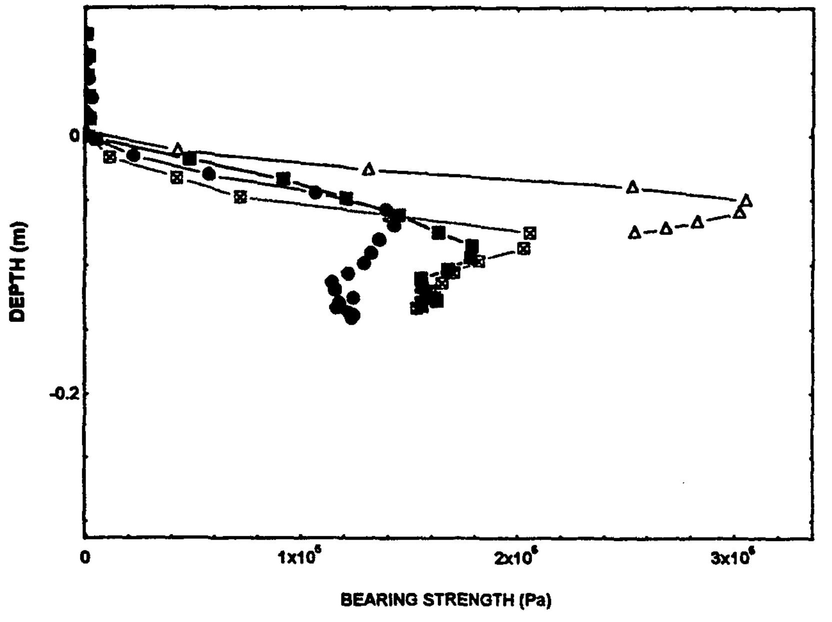

Figure D-9. Bearing strength profiles from multiple ESP drops at station 9601, on 15 August 1996.

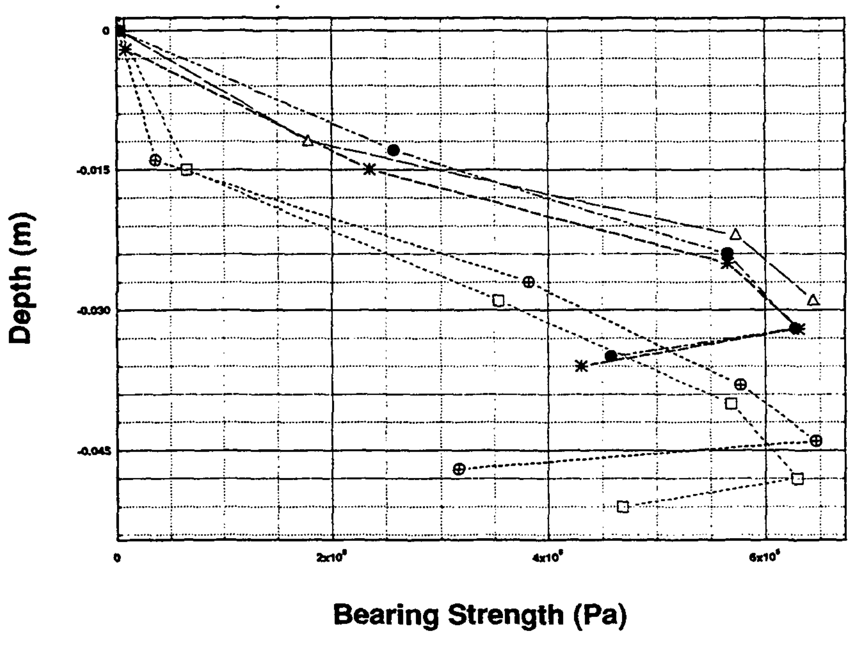

Figure D-10. Bearing strength profiles from multiple ESP drops at station G31.

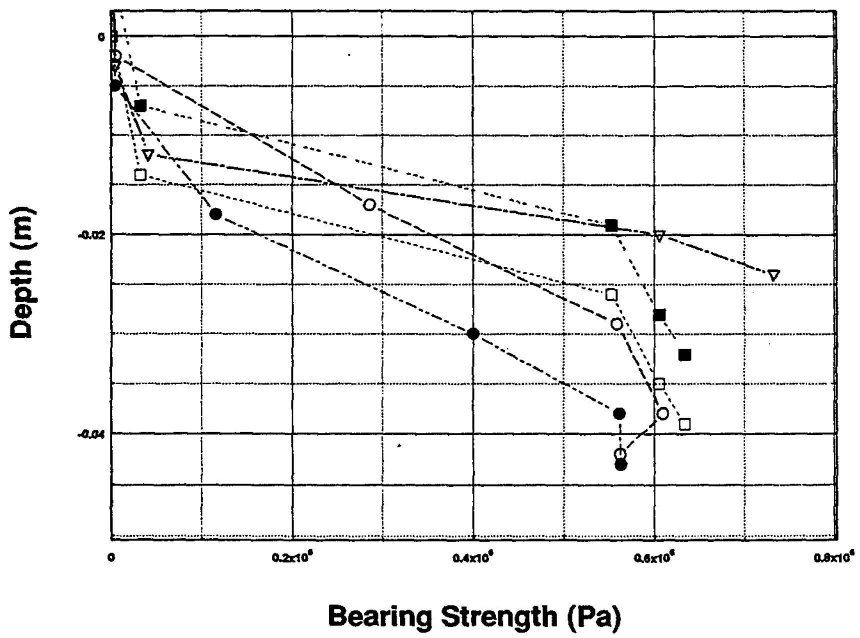

Figure D-11. Bearing strength profiles from multiple ESP drops at station G32.

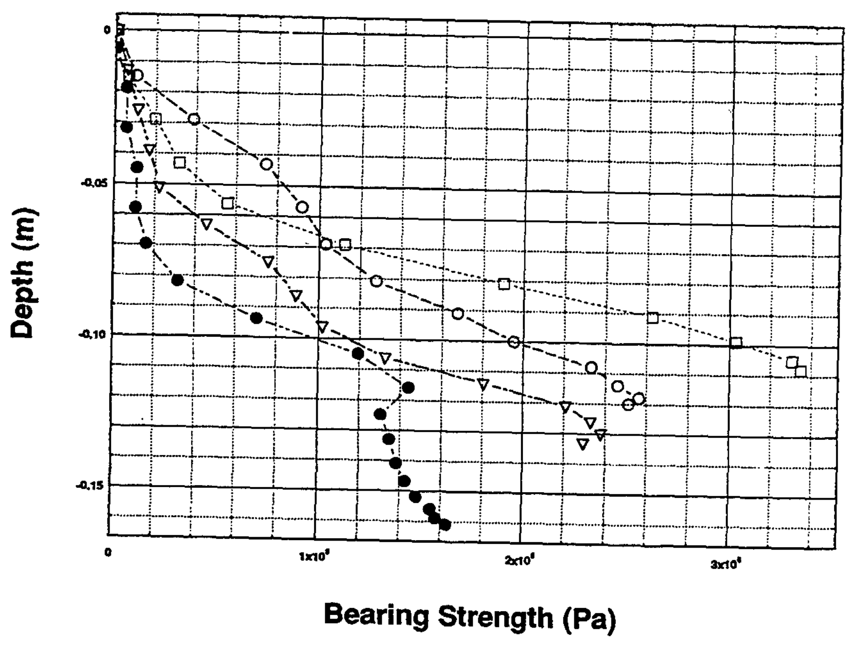

Figure D-12. Bearing strength profiles from multiple ESP drops at station G33.

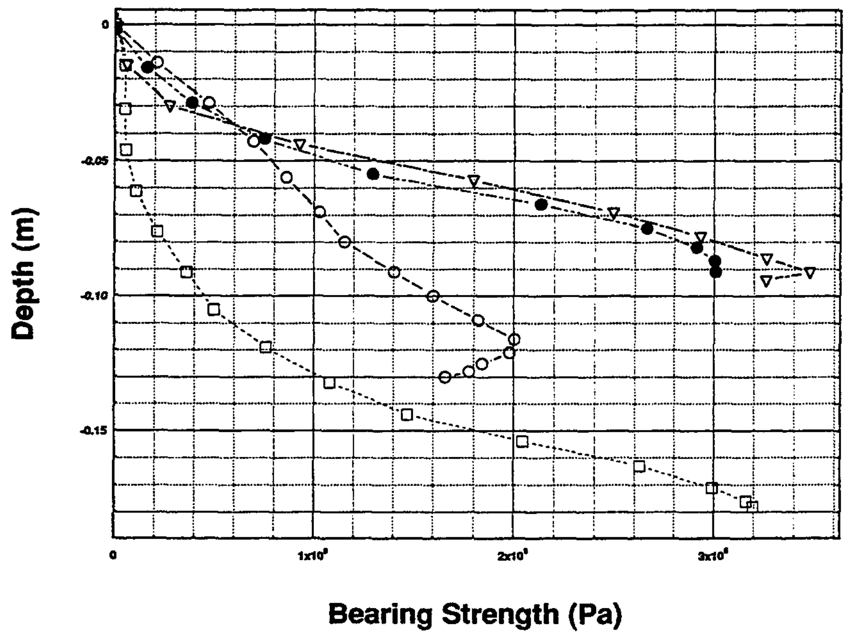

Figure D-13. Bearing strength profiles from multiple ESP drops at station G34.

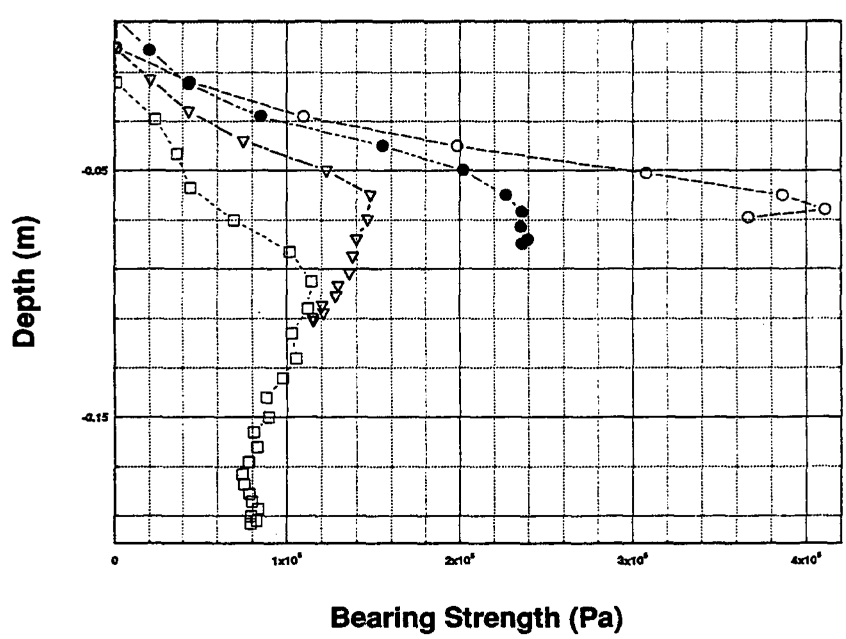

Figure D-14. Bearing strength profiles from multiple ESP drops at station G35.

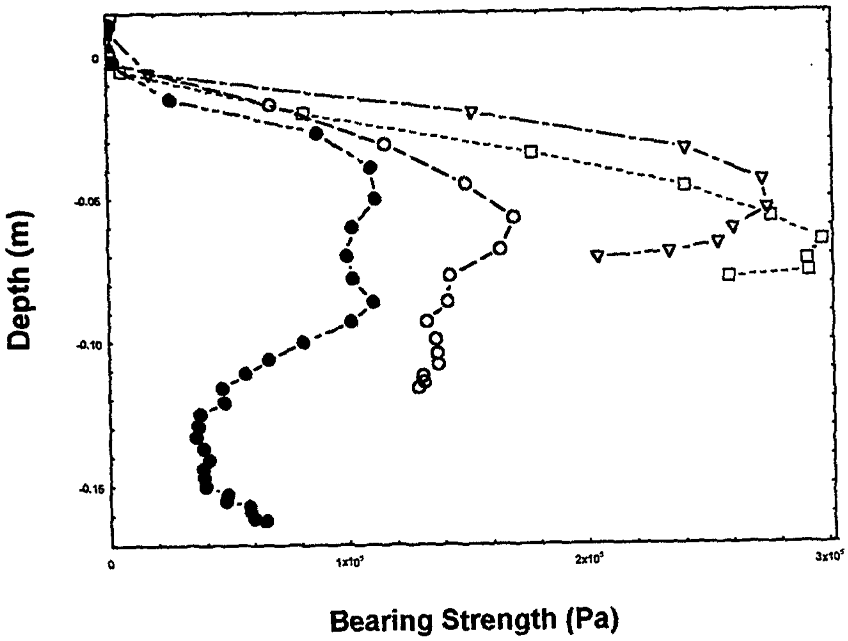

Figure D-15. Bearing strength profiles from multiple ESP drops at station G36.

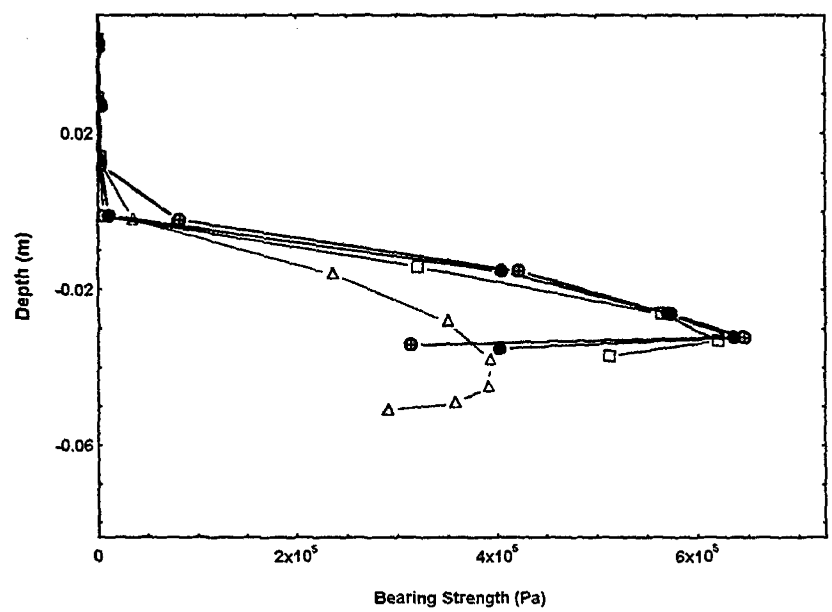

Figure D-16. Bearing strength profiles from multiple ESP drops at station G38.

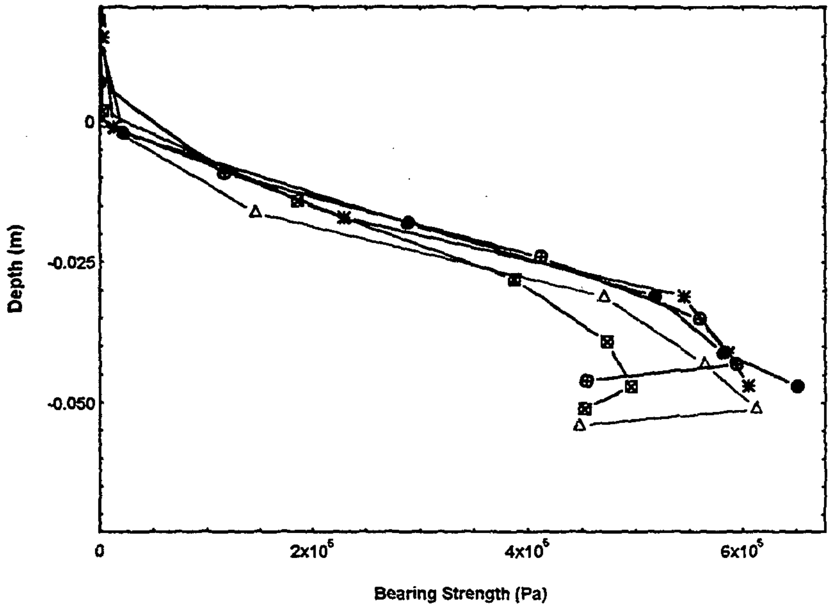

Figure D-17. Bearing strength profiles from multiple ESP drops at station G39.

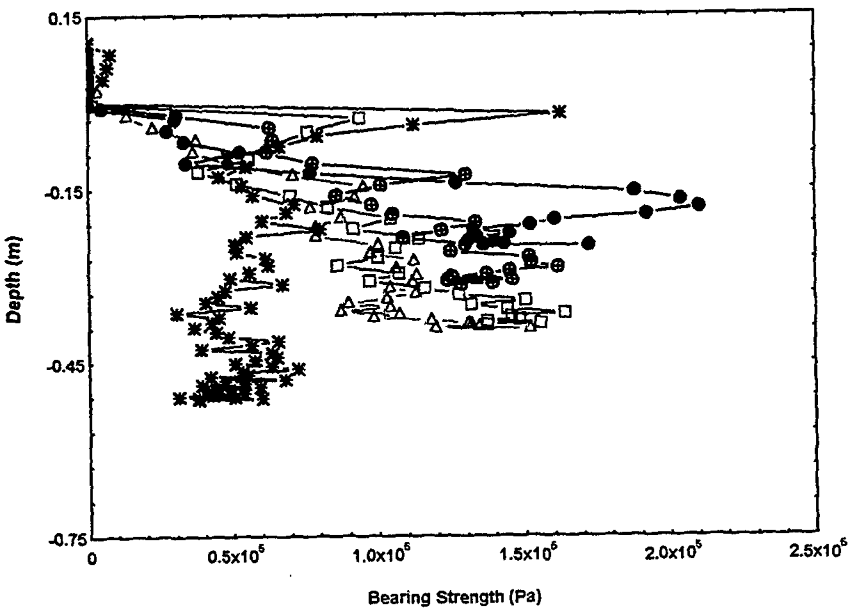

Figure D-18. Bearing strength profiles from multiple ESP drops at station G40.

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(A Report on Data obtained in August 1996)

P. J. Mulhearn*, J. Boyle* and F. G. Crook+

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19. ABSTRACT

This report describes the properties of sediments off Cairns, North Queensland, obtained from samples gathered during trials with A.M.s Brolga and Bermagui in August 1996. These data were obtained in a survey of seabed properties to determine suitable sites and transects for TTCP trials of environmental reconnaissance techniques, which occurred in April/May 1997. The data are relevant to mine burial, acoustic propagation and high frequency reverberation, all important factors in mine warfare. The results form a worthwhile addition to the Mine Warfare Systems Centre and Australian Oceanographic Data Centre data bases, especially as the Cairns area appears to be typical of much of North Queensland's eastern coast and the data herein include much information on sediment shear and bearing strengths, parameters which are critical to impact burial but which are rarely measured.